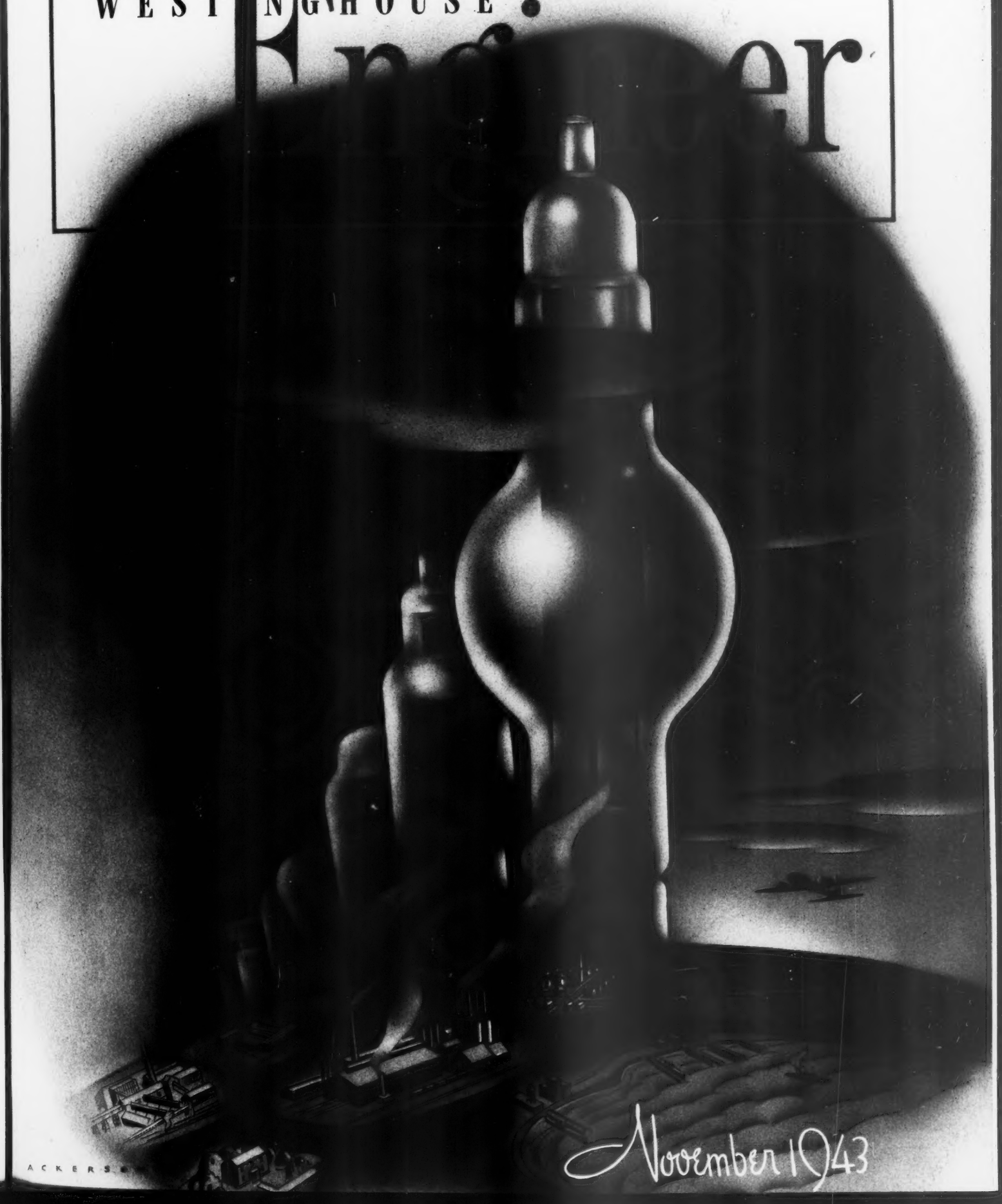
WESTINGHOUSE

Engineer



November 1943

Electrons

BY THE OUNCE OR BILLION

The electrical engineer is accustomed to thinking of the products with which he deals in terms of amperes, volts, and kilowatts. His "goods" are, fundamentally, electrons, and it would be possible—albeit more cumbersome—to deal with their numbers, mass, charge, and velocities. It would be perfectly correct, for example, to say that a 10 000-ampere rectifier in a year's time pumps through each of its direct-current terminals approximately 63 ounces of electrons. In terms of numbers of electrons the figure is so gigantic as to be beyond comprehension—2000 billion billion billion.

* *

A customer of the electric-power company buys electricity by the kilowatt-hour. But what the electrical men actually do is to cause electrons to move back and forth short distances in the wires of his house or factory. In terms of numbers of electrons the figure is large; in terms of weight it is surprisingly small. Assume a domestic customer who uses 115 kwhr (at 115 volts) per month, which is somewhat more than the national average. An electron turnstile at his meter would count in one month a total of 22.6 million billion billion electrons going back and forth (in both directions because the current is alternating). This is the total number (neglecting normal random movement) passing a given point. But these 22.6×10^{24} electrons weigh only 725 millionths of an ounce. At this rate, the electrons surging into and out of the circuit of our 115-kwhr-per-month customer for 1150 years would weigh but an ounce. Because one of the two variables in the power bill (voltage) is assumed constant it can be considered that he pays a penny for each 65 000 billion billion electrons pumped into and out of his circuit, or at the rate of about 4750 dollars an ounce.

* *

The electronic merchant, unlike other merchandisers, always has as many electrons left after a sale as he had to begin with. Electrons are never used up or consumed. As many electrons, on the average, leave a customer's circuit and return to the power-supply system as the generator pumps into it. The Grand Central Terminal analogy is perhaps better than the usual hydraulic analogue. In any one day (cycle) thousands of people (electrons) come in in the morning and go out at night, so that the average net total is zero, but meanwhile the work of the day has been accomplished. At any particular moment people are seen scurrying about in all directions (random movement). Add some greater attractive force (potential) such as a convention, or show, or work and many more people will stream in, only at the end of that cycle all these people, on the average, have returned to their starting point—but more has been done.

* *

The formal definition of current is based on electrolytic action, i. e., amount of electricity required under specified condition to deposit so much silver. This may lead to the notion that current flow is inseparably linked with the passage of electrons. This is not always so, because of the phenomenon of displacement current, which is just as real as electron current. Thus, in a transformer, current flows through the secondary as the result of current in the primary, but no electrons pass between them. Likewise, in a vacuum condenser no electrons would pass across the space between the plates but current would flow.

* *

The extreme speeds with which electronic devices can start, stop, or vary current—in times measured in millionths of a second—result simply from the high ratio of charge on an electron to its mass. A grasshopper can jump hundreds of times farther than a man on any comparative basis simply because its ratio of available force to mass is much higher. With electrons, both quantities are small but the ratio of charge to mass is enormous. This is indicated by the relationship of repulsion forces between given masses of electrons. If it were possible to concentrate a pound of electrons at each pole of the earth the force of repulsion between them would be ninety million million tons, equivalent to the weight of two billion of our biggest battleships. Two one-ounce concentrations separated by one foot distance would oppose each other by a force of 3650 million million tons.

* *

Lest engineers obtain any smug ideas about their ability to push electrons around through wires it should be pointed out that the best they can do is to modify only slightly the random movements of electrons. In fact, the random current density, or current crossing a unit surface in a metal because of random electron velocities, found by counting the electrons crossing in one direction and neglecting the equal number crossing in the reverse direction, is approximately 10 000 billion amperes per square centimeter.* The exact value depends upon the metal, and only to a slight degree upon its temperature.

* *

The velocity with which electrons move even in fields of moderate strength is very great. An electron moving between electrodes having a difference in potential of only ten volts will attain a velocity of over 1160 miles per second (over four million miles per hour). This incidentally gives a convenient unit of energy, because the mass of an electron at rest is a constant. An electron volt is the energy of an electron acquired by moving through a potential difference of one volt.

*"Applied Electronics" by M. I. T. Staff, p. 67.

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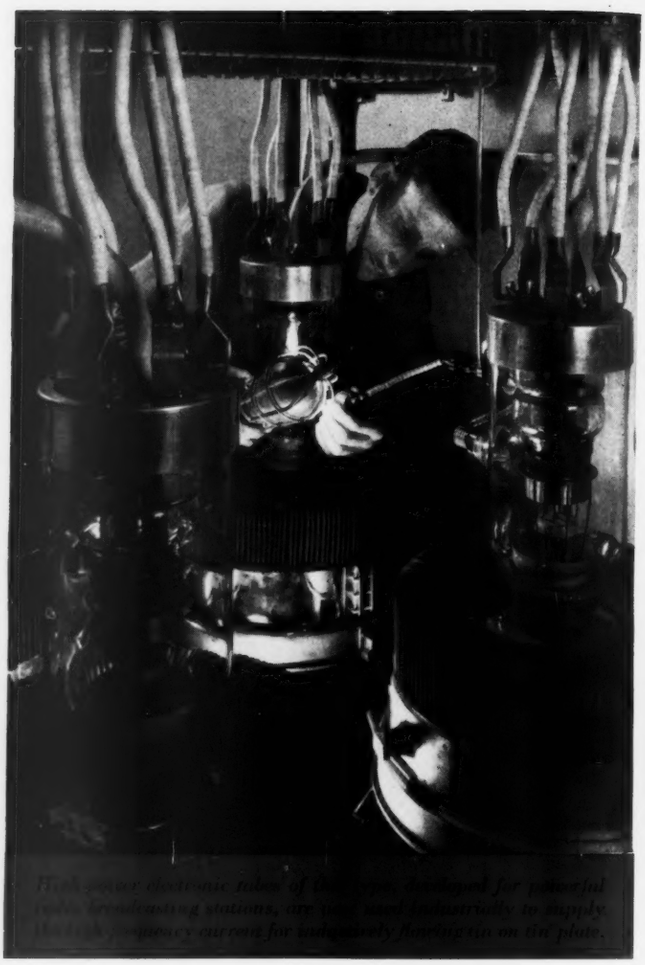
Electronics in Industry

Electronics is causing unspoken uneasiness among many engineers of the "power" school. Has electronics, long associated with radio, suddenly developed into a full-grown industry, the principles of which they have only the haziest notions and which, as some claim, will outmode their kind of engineering? Electronics is, indeed, an important and rapidly growing branch of the electrical industry that every alert engineer will diligently study —but much of it is not as unfamiliar as at first might seem.



High-power electronic tubes of the type developed for powerful radio broadcasting stations, are now used industrially to supply high-frequency current for induction heating in tin plate.

ELECTRONICS is a much used and much abused word. The term, thrust onto the center of the engineering stage by the needs of war, has been considered fair game by all, and there are almost as many definitions as there are definers. But the air is beginning to clear. Among the attempts by many companies and engineering bodies to perform the necessary job of stating the scope of the term there is increasing agreement that it applies to the action of electrons in gases or in vacuum in contrast to the flow and effects of current within solids.

Essential to a clear understanding of the nature of electronics and its place in the electrical-engineering scheme of things is a brief review of events that have led to the present use of the term. Electronics clearly has to do with the behavior of electrons, the word electron having been used first by Dr. G. Johnstone Stoney, in 1891, as a name for the natural unit of electricity. Obviously, any such definition of electronics will not do because it covers too much territory. It includes, in fact, the whole field of electrical engineering. The electric motor, the incandescent lamp, and every other electrical device are but means of controlling the action of electrons to useful purpose. Of necessity, therefore, an arbitrarily restricted definition must be set for the term electronics. This limited meaning has been slowly evolved out of the environment surrounding its development.

The invention of the Fleming valve or vacuum tube in 1905 and the discovery of the possibilities of the control grid by de Forest in 1907 set the stage for radio broadcasting. The vacuum tube was frequently referred to as an electronic tube because in it electrons departed from the confines of solids and were ejected into partially evacuated space within the tube. The electric-power industry was firmly established before the electronic theory of matter or the properties of the electron were known. In dealing with vacuum tubes, on the other hand, the concept of electrons as discrete particles was important. Logically enough, the science of the application of these vacuum tubes was spoken of as electronics.

For many years, nearly the only use for electronic tubes was in connection with radio communication. The term electronics became associated with radio. The notion that electronics has to do primarily with communication still persists.

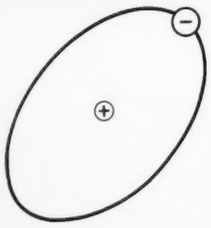
In the middle and late 20's the electronic tube began to find many applications not associated with its first love, radio. Now a tube in a home radio receiver may also be used in a motor-control device. Some of the tubes in a broadcasting station are identical to those working in a tin-plate mill. It would seem, then, that electronics cannot be described by the job done, but by some distinguishing characteristic of the devices themselves.

The early two-electrode and three-electrode vacuum tubes proved to be only the first of an extraordinary prolific family. There came the tubes with four, five, and even more electrodes, various forms of thyratrons, ignitrons, light-sensitive tubes, and others that do not remotely resemble the progenitors of the electronic line. Glass walls gave way in many cases to envelopes of metal. Tubes took every imaginable shape. The degree of vacuum varied with the tubes and their use, some tubes even using gas under low pressure.

Through all of these variations in form of the electronic tube a single, basic distinguishing feature remains. Electrons by one means or another are induced to leave their normal habitat—the interior of a metal—and move about in the surrounding gas. This gives a simple, easily understood test for electronics that anyone can apply. It can be stated this way. Electronics is the science that deals with the emission of electrons and their action in vacuum or gases.

The Principles of Conduction in Solids and in Gases

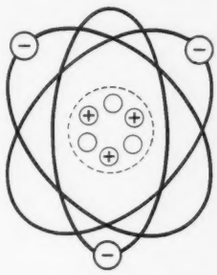
According to the nuclear theory of matter, each atom is made up of neutrons, protons, and electrons. (We can ignore the fact that physicists now tell us there are also positrons,



mesotrons, and neutrinos.) The proton is the positive unit of electricity. It is smaller but much more dense and it is 1837 times heavier than the electron. The neutron has almost exactly the same mass as the protons but has no electrical charge; it is neutral. The electrons in the atomic structure swing around the nucleus in orbits of relatively great radii. The higher the order of the element in the periodic table, the heavier is its nucleus, the greater the total number of electrons, and the more orbits or shells. The number of electrons normally required to fill the successive orbits differs. The first orbit is filled with two electrons; the second will hold 8; the third, 18; then 32, 18, 18, and 2, with 92 being the maximum.

In normal electrical science it is these outer orbital electrons that concern us, for it is they that can be dislodged to form "free" electrons, the "substance" of conduction current. Normally these orbital electrons are also strongly bound to their nuclei by interatomic attractive forces. In metals, however, the atoms are close together in a regularly formed crystal lattice.

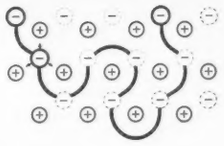
Because of the proximity of the atoms an outer-shell electron can be attracted by several neighboring atoms. Consequently the hold of a nucleus for one of these distant electrons in the outer shell is quite small. In this way some of the outer-shell electrons can then move beyond their regular orbits. Because these electrons are not bound to the nucleus of any atom at certain intervals they are known as free electrons.



In good conductors, particularly the metals, these free, outer-shell electrons engage continuously in random movements from atom to atom. There are vast numbers of them in a copper conductor. Exactly the opposite is true of an insulating material, in which electrons are bound tightly to their atomic systems. This prevents the free movement of electrons from atom to atom.

When a potential is applied to the terminals of a metal conductor there is started an *average* drift of the free electrons in the direction of minus to plus (which is just opposite in direction assumed by convention for current flow). This drift constitutes electric current, and when the electrons passing a given point in one direction exceed by 6.28 billion billion (6.28×10^{18}) the number passing in the other direction each second, one ampere is said to flow.

Obviously in a solid conductor no single free electron drifts far before it meets some atom and becomes a part of its structure. At the same time another electron may be leaving that same atom to become—also for a short distance—a part of the electron drift, i.e., current flow. Thus, electric current can be considered a kind of relay race, participated in by vast numbers of free electrons. The actual average forward movement of electrons along a wire is quite slow, probably not more than a few inches per minute, although the electric effects resulting from this drift moves with the speed of light. Herein lies one major difference between conduction in solids and electronics, i.e., electron flow in gases. Electrons move from point to point in vacuum tubes like bullets at terrific velocities.



One of the foundations of conduction in gases is the phenomenon of electron emission. At room temperature the movements of electrons are confined within the boundaries of the metal. Virtually no free electrons are able, without some special aid, to leave the surface, because they do not have enough energy of their own to escape the pull of the positively charged nucleus. At the surface, the positive charges of the atoms create a potential sufficiently strong to act as a barrier, restraining the electron to the confines of the metal. A relatively great deal of energy is required for an electron to break away from the surface of a solid. The definite, critical amount of energy required for an electron

to escape to the surrounding gas is called the work function, and is different for each material.

There are in general four ways by which an electron can be given this energy required to leave the surface, i.e., for electron emission. One is by the addition of heat. As the temperature of the solid surface is raised by any means, the thermal agitation of the free electrons increases. If the temperature becomes high enough, some of the electrons are given, by mutual bombardment, energy in excess of the work function. Thereupon they leave the surface, called the cathode. This is thermionic emission. These electrons, if no other

The Mot-o-trol, an electronic motor-speed control, has the ability to control the cutting-tool drives on heavy machine tools. It also has the smooth precision required for controlling the speed of machines winding delicate wire coils and foil for capacitors.

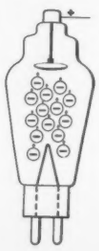
electric influence is present, hover in a cloud about the cathode eventually reaching a stable condition in which as many electrons fall back into the surface as are leaving it. This boiling out of electrons from a hot surface was a phenomenon noticed by Edison in his early experiments with the incandescent lamp.

In addition to thermionic emission there are three other types of emission. One is secondary emission, in which the electrode is hit so hard by a stream of electrons or other high-velocity particles that the free electrons in the cathode surface are given the necessary energy to escape the positive attractive forces of the atoms. This type of emission is usually avoided instead of encouraged. Some tubes have a special grid, known as the suppressor grid, to overcome secondary emission. There are, however, a few special cases as in "electron-multiplier" tubes where secondary emission is put to useful purpose.

Some types of materials are such that when struck by light the energy absorbed by the surface free electrons is sufficient to permit emission. This is termed photoelectric emission and is, of course, the principle upon which phototubes operate.

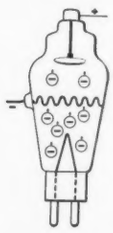
Finally, it is possible to pull free electrons directly out of a solid surface by an intense electrostatic field at the surface of a material. In other words, the attractive force of the positive atoms at the solid surface is exceeded by that of the applied field and the free electrons have no other choice but to leave. This is what takes place in the ignitron.

If, inside the same enclosure with the hot cathode, there is placed another electrode positive in polarity with respect to the cathode, the emitted electrons proceed to this positive electrode, or anode, with velocities of the order of several thousand miles per second. This, then, constitutes a current flow in a gas.



This simple, two-element tube is called a diode, or rectifier tube, and is ordinarily used as a rectifier of alternating current. The anode being cold, or relatively so, does not emit electrons, and hence there can be no electron flow from anode to cathode. Thus, current can flow between the electrodes in only one direction, and that when the anode is positive with respect to the cathode.

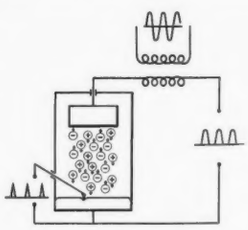
The greatest step in the field of electronics was taken when de Forest placed a third element between the cathode and anode. This electrode is an open mesh or grid of wires placed much closer to the cathode. Any positive potential on it will have many times greater effect than the corresponding potential on the anode for speeding the emitted electrons away from the cathode, through its open mesh, and on to the anode. Likewise, a very small negative potential applied to the grid can overpower a fairly large anode potential and reduce the electron flow or stop it altogether. Thus, the grid provides a means of controlling, with relatively small voltage change and almost no energy consumption, an enormous range of electron flow between cathode and anode. This three-electrode vacuum tube then is a powerful amplifier.



Outstanding Members of the Industrial Electronic Family

The Ignitron—Aside from communication devices, the electronic work horse in this war undoubtedly has been the ignitron. This is the mercury-pool type of rectifier that has supplied the bulk of the direct-current power for the production of aluminum and magnesium.

The present activity in the pool-type rectifier began in 1932 with the announcement of the igniter principle. It was found that if potential is impressed across some high-resistance material, such as carborundum, a high potential gradient is created across the material, resulting in ionization of the surrounding vapor. This leads to the formation of the cathode spot on the mercury surface, necessary for the establishment of electron emissions and the flow of electrons across the evacuated space from the mercury cathode to the anode when the a-c line voltage is applied.



The igniter principle of starting the arc is so simple and so sure that the arc is deliberately allowed to go out at each current zero and the arc "rekindled" again one-half cycle later. This solves a lot of problems present with the multi-anode type of rectifier in which a common mercury pool served as the cathode for several anodes in a single tank.

Here it was necessary to maintain some ionized mercury vapor present at all times so that the arc starts itself every other half cycle. This introduced problems of complicated baffling to keep the anodes from short circuiting each other. Also with the igniter principle the anode can be placed closer to the cathode, with a corresponding smaller voltage drop. Because the power loss in a rectifier is the product of its current times the voltage drop through it, the ignitron has an efficiency much higher than that of conventional rectifiers.

Ignitron Welding Control—In developing its igniter principle the primary objective was to provide an improved power-conversion device and one that would be freer from arc backs (those random reversals of current) that had so long plagued the mercury-arc rectifier. The igniter gave such a facile method of starting an arc that other valuable uses were quickly seen for it. It became the foundation stone of spot welding in which currents are released for very short and very precisely measured periods of time—for a fraction of a half cycle to many cycles. The ignitron becomes an electronic switch in which heavy currents are started and stopped at will without the noise and display of arcs interrupted in air.

High-Frequency Heating—In no field does electronics have a greater opportunity for expansion than in high-frequency heating. As is true throughout the field of electronics, the principles involved do not differ from those dealt with in power frequencies. It is simply that as frequency is increased —to several hundred, to several thousand, and even to several hundred thousand—the factors of skin effect, eddy currents, dielectric losses become increasingly exaggerated and the high-frequency heating engineer simply turns them to useful purpose.

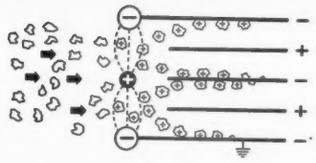
Outstanding recent use of induction heating is that of melting electrolytically deposited tin on tin plate to obtain a bright finish. Frequencies of the order of 200 000 cycles per second are used, power being generated by electronic tubes.

At very high frequencies—a million cycles or more—the dielectric or power-factor losses in non-conducting materials become really significant. This method of applying internal heat in the rapidly growing business of curing of plastics, and bonding of plywood, is being used to a fast increasing extent.

Carrier Current—The transmission-line engineer has used carrier current as an effective tool for two decades. With it he can transmit relaying, supervising, metering, or communication signals over the transmission conductors themselves, thereby saving the expense of separate lines.

Carrier apparatus is clearly a first cousin to radio equipment. High-frequency current is produced by electron-tube equipment essentially as it is done in a broadcast transmitter. This carrier wave is modulated in some suitable way for relaying indications, supervising signals, metering impulses, or by audio waves, and introduced onto the transmission conductors inductively. At the receiving end of the line the process is reversed.

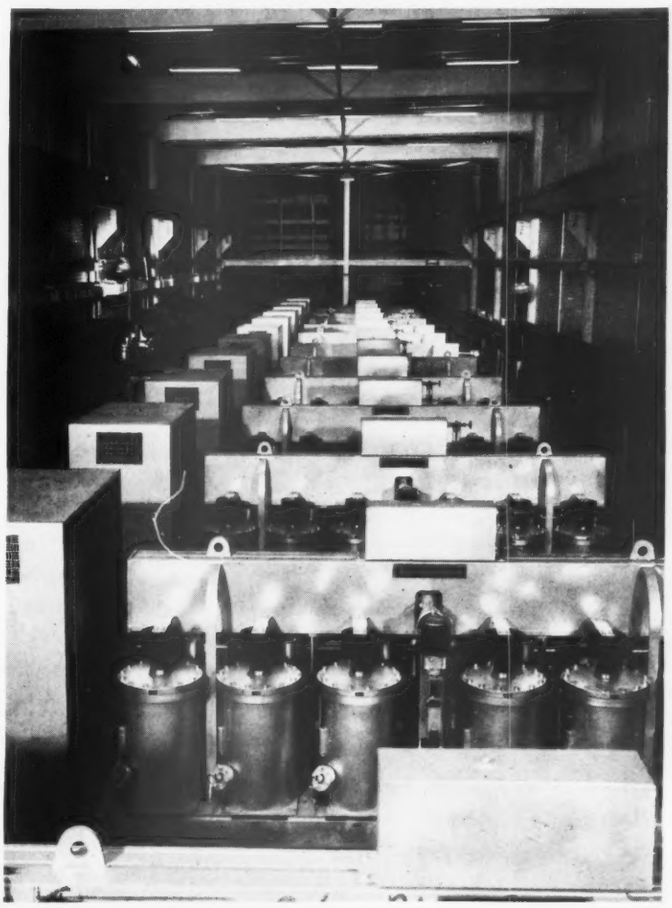
Dust Collecting—Electronics has given its attention to dust collection. In the Precipitron electrostatic air cleaner dusty



air is first blown through a strong electrostatic field, whereupon each solid particle is stripped of one or more of its free electrons, leaving it positively charged. The ionized dust particles are carried on through this ionizing zone by the air into the collecting chamber, which consists of the alternate positively and negatively charged plates. Here the particles, carrying a positive charge—being deficient in electrons—are drawn out of the air stream to the negative plates where they adhere for subsequent removal.

The actual ionization of the dust particles is an electronic action. Also, the high direct-current voltages required (12 000 volts in the ionizer and 6000 volts in the collector) are produced by vacuum-tube rectifiers in the power pack.

The Fluorescent Lamp might not be recognized as an electronic device, but it most surely is. A fluorescent lamp is a hot-cathode device in which electrons are caused to flow between electrodes, one in each end of the lamp. To start the electron emission both electrodes are preheated by the starting device before the voltage is impressed across them. Electrons passing through the mercury vapor give up energy to the mercury vapor in the lamp, causing it to reradiate energy in the ultraviolet spectrum. This invisible radiation strikes the inside glass walls, which are coated with phosphors that have the ability to transform the energy into visible light at high efficiency. The production of light by this double conversion process is accomplished at an efficiency two to three times that of the ordinary incandescent lamp.



The tremendous war demand for magnesium and aluminum has been met by electrolytic production of these light metals. The heavy currents at low voltages needed by producers have been largely supplied by banks of ignitrons.

The Precipitron, an electrostatic air cleaner originally designed for cleaning air in homes, is performing yeoman service in many industrial applications. Removing the smokes and oil mist from the air about high-speed machine tools, cleaning blast-furnace air, keeping the windings of rotating machines clean by cleaning the blast of cooling air, are but a few of the industrial chores that this electronic equipment now shoulders.

The Sterilamp—Closely related in principle to the fluorescent lamp but entirely unlike it in function is the Sterilamp. Ultraviolet radiation, predominately in the 2537 Angstrom bond, is produced in a long, slender tube by electronic action, much as it is in the fluorescent lamp. But unlike the fluorescent lamp, the ultraviolet radiation in the Sterilamp is the final useful product. The radiation is used to kill bacteria instead of to produce light. In the fluorescent lamp none of the ultraviolet radiation escapes because it is transformed into longer wave lengths by the phosphors and because it couldn't get through the lime-glass walls anyway. In the Sterilamp the walls are made of a special kind of glass that allows the short-wave radiation to pass through.

The Electric Eye—The photoelectric tube, which has so fascinated people generally by its many seeing jobs such as counting, sorting, inspecting, color discriminations, and light control, is one of the simplest of electronic devices. A phototube is an evacuated glass envelope containing a single pair of electrodes. One of the electrodes is made of a metal that causes it to emit electrons as explained in the discussion of photo emission. With potential applied across the electrodes and with light striking the photo-sensitive surface, current flows through the tube, which can be amplified and used in any desired manner. Shut off or reduce the light and the current flow stops because the electron emission stops. The photoelectric tube is a light-actuated current valve.

Electronic Controls—The control engineer makes use of rectifiers, thyratrons, ignitrons, phanotrons, and scores of other multi-electrode, gas-filled and evacuated tubes as readily as he does resistances, contacts, switches, relays, and copper. One of the most recent electronic controls is a device called a Mot-o-trol for providing, from alternating-current lines, the wide range of direct-current voltages required for a wide-speed-range, direct-current motor. The electronic equipment takes the place of the variable-voltage motor-generating sets in the lower range of motor sizes, which, as the ignitron before it, has the merit of replacing rotating equipment with a stationary device.

Other combinations of electronic tubes and control equipment are in use to keep the speed of motors constant regardless of voltage load fluctuation, to hold generator voltage constant, to close automatically the synchronizing switch between alternating-current generators, or systems when the speeds and phase relations are just right and not before.

In the cathode-ray oscillograph a beam of electrons shot from a hot cathode is made to impinge on photographic film or a fluorescent screen, leaving a visible trace. Because the electron beam can be deflected by electromagnetic or electrostatic fields it can be made to write on the film or on the screen a trace of voltage and current behavior in a circuit. By this means electrical phenomena existing but a fraction of a millionth of a second can be photographed for permanent record or slow-speed recurring waves projected on a fluorescent screen for visual study.

Akin to the oscilloscope-type of cathode-ray oscillograph is the iconoscope, the tube that forms the heart of present-day television systems. Here a beam of electrons, controlled in intensity corresponding to the lights and darks of the televised scene, is made to sweep across a fluorescent screen so rapidly that the image of the complete picture is registered by the eye.

All in all, electronics is a fast-moving art. That it will replace many of the older forms of power equipments for many functions is questionable, but that it will have a much larger place in engineering mostly by expanding its services cannot be denied. Electronics is not inherently mysterious or difficult to understand, except for those who do not take the opportunity to study it.

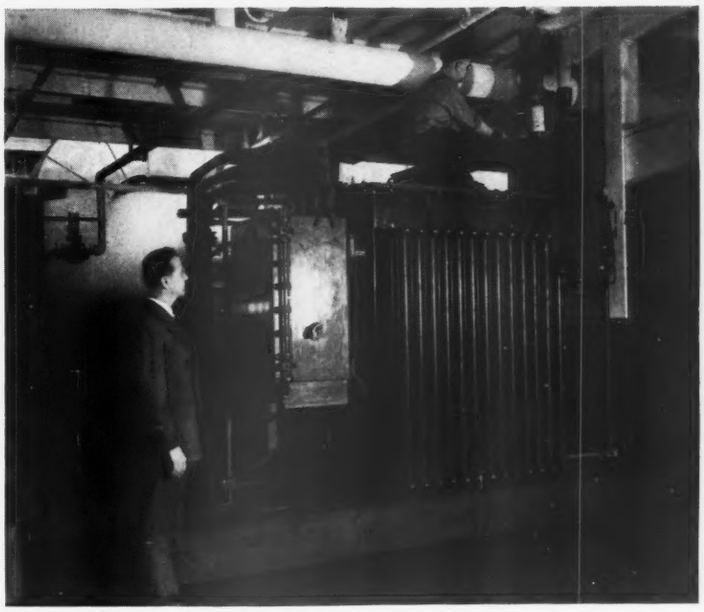
The Secondary Network Proves Its Flexibility

In man or machine, one of the most treasured qualities is adaptability to changing conditions. The secondary-network system of power distribution was subjected to such a test of character in a propeller manufacturing establishment. By a reshuffling of standard network units, the system was able to keep pace with changes in product, a series of increases in loads, and finally, a major rearrangement of plant manufacturing facilities—all accomplished without service interruption.

C. E. PFLUG
Plant Engineer, Propeller Division, Nash Kelvinator Corporation

MUCH has been claimed for the flexibility of the secondary network as a power-distribution system for industrial plants. In our plant at Lansing, Michigan, re-equipped to build variable-pitch propellers for military planes, we had opportunity to test this claim, to a degree we little realized when the decision was made to install a secondary-network system.

When our firm was designated by the government as a manufacturer of Hamilton Standard propellers, three idle buildings totaling 450 000 square feet of floor space previously used for automobile manufacture were available. One had been a single-story shipping shed (Building B), and the other two were three-story structures, a warehouse (Building A), and a small paint-storage building (Building C in rear of Building A). This latter building presented no power-load problem because of its relatively small power requirements. The interior of the buildings had to be completely re-equipped and supplied with new services—heating, sprinklers, sewers, gas, compressed air, and ventilation. Also, a complete new power-distribution system was required.



Mr. Pflug overseeing a transformer installation.

The decision as to what type of electrical system to provide was made difficult by the lack of complete information at that stage of extent, amount, and locations of the electrical loads the manufacturing operations would entail. Based on our experience as automobile and refrigerator manufacturers and drawing on the information made available by the Hamilton Standard Propeller Company, it seemed likely that the load would be constant throughout a 24-hour day. The total load was estimated to be approximately 3000 kw of power and 600 kw of lights.

Because time was an important factor, the electrical equipment had to be purchased before plant-layout plans were made. The distribution system therefore must be flexible enough to take care of all loading conditions that might arise. A bus-duct system was chosen to provide power for the entire first floor and such other parts where manufacturing might take place. With the uniform bus-duct system the feeders into the ducts could be connected at convenient intervals, depending on where the concentration of load fell.

The power system considered first was the conventional secondary radial with the entire substation located at one place, and secondary feeders radiating from there. The substation was to be located at one corner of the factory. However, with this arrangement the cost in copper and switches would be prohibitive and the voltage drop excessive.

The unit-substation system with a double primary and with tie lines between substations was considered next. The ties were necessary to transfer surplus power from one substation to another and to accommodate indeterminate power load demands.

The third system considered was the industrial secondary-network system with two radial primary circuits connected to each transformer.

This system was selected for several reasons: (1) The equipment could be obtained more quickly, (2) the price was comparable with the other two systems for our particular installation, and (3) this system had the flexibility necessary to a new factory where production methods were subject to change.

In 1941, when this work was being done, the network system with 480-volt secondary had not been tried in industrial service. Only network systems with 220-volt secondaries had been in use industrially up to that time. However, this type of system had had a thorough trial in the utility field, and had proved satisfactory and reliable. Quicker availability of apparatus became a strong factor. The system, as originally laid out, consisted of five Inerteen-filled, 750-kva transformers with two 500 000-cm, 4160-volt primaries to each transformer. A throw-over switch was provided so that the load could be transferred from one feeder to another under

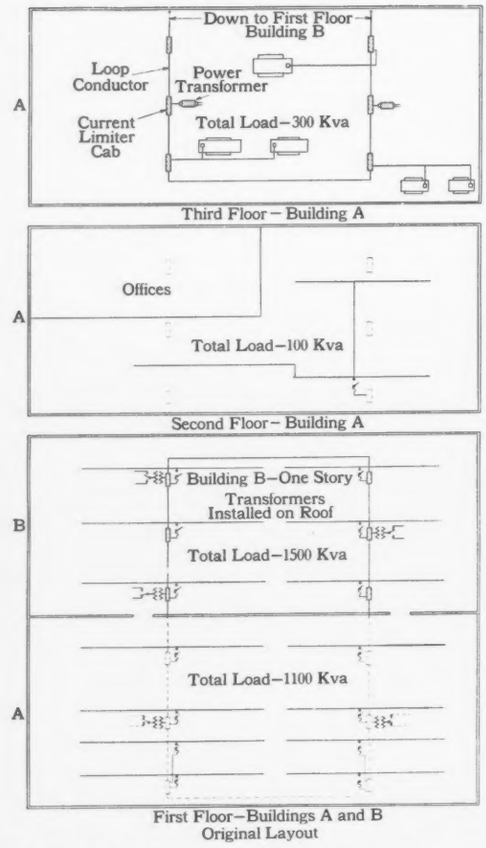
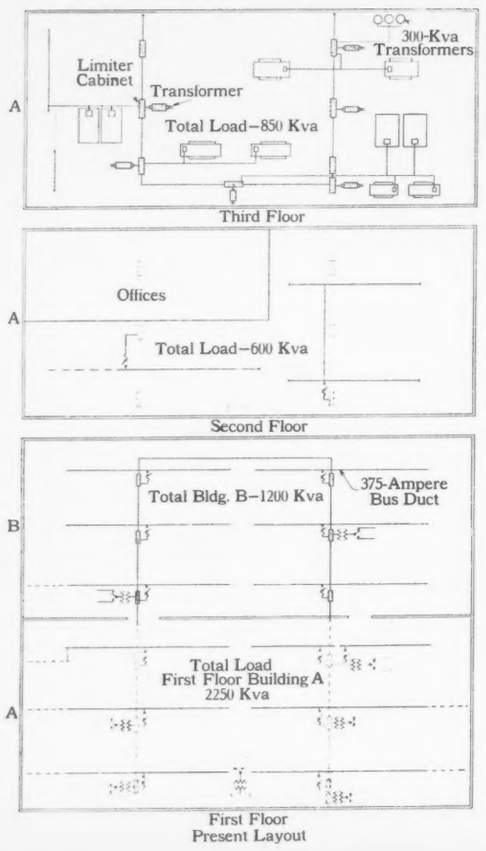


Fig. 1—***Original layout of buildings*** **A** ***and*** **B.**

Fig. 2—***Present layout of buildings*** **A** ***and*** **B.**



no-load conditions. An interlock operating between the standard secondary-network protector and this throw-over switch was provided to prevent any error in switching that might jeopardize the safety of the equipment.

The system was designed to operate under fault conditions as follows: The transformer, or primary failure, would result in the opening of the feeder at fault. This would throw all of the load on the other feeder. When this occurred the transformers not at fault would be transferred to the other feeder and all the load carried in that way. The overload resulting on the transformers or feeder would be of such short duration that harm could not come to the equipment. It was therefore unnecessary to over-transformer the system as is usually necessary in a network system.

The network loop was to have a capacity equal to an individual transformer and would consist of three 350 000-cm circuits in parallel protected with current limiters. Twelve limiter boxes were to be inserted in this loop at convenient intervals, from which loads should be taken and into which transformers would supply power.

The main incoming substation was located on the second floor of the three-story Building C. Two primary circuits with adequate oil circuit breakers fed the system. In the storage building (Building B) adjoining Building C two transformers were located on the third floor along with six limiter boxes. The secondary loop connected these limiter boxes and ran on the ceiling on the floor below. The bus-duct feeders ran straight down to the bus duct on the first floor. Because the transformers were Inerteen filled, fireproof transformer vaults were unnecessary.

On the roof of the one-story building (Building B) were placed three transformers and six limiters. The loop followed the roof trusses. The bus ducts were directly below. Here, platforms were built into the regular roof trusses. A hatch was provided in the roof so that the transformers could be pulled up with a winch and cable. When in its top position, I-beams were placed under it for support and the transformer was in place. The typical limiter box contained twelve sets of limiters, three for each tie line, both in and out, three for the transformer connections, leaving three for feeder circuits.

Lighting was supplied from a separate primary circuit of a conventional radial system.

Operating Experiences

The usual faults in the wiring and construction gave some indication as to the operation of the limiter-protected network system. For example, a fish tape was pushed through a conduit across the energized bars in the bus duct. A 400-ampere fuse burned out, but power was not interrupted. The failure of a safety-switch insulator caused bus fuses again to blow, without interrupting service. In both cases the faults occurred at a point close to the fuse switches that protected the bus duct and were subject to relatively high interrupting current.

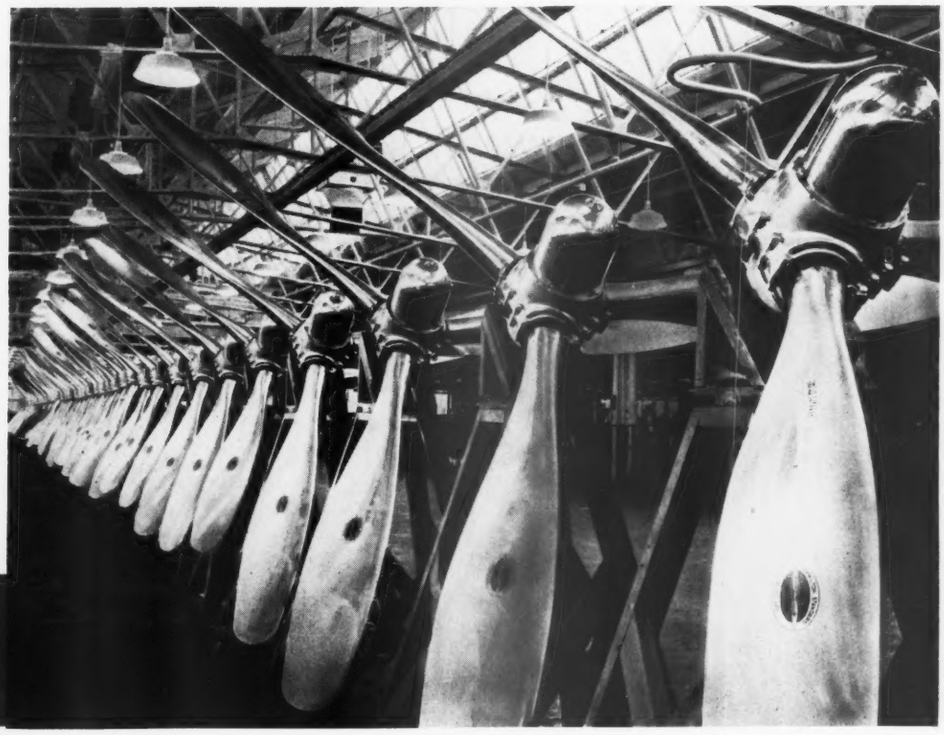
No fault in the system has yet occurred to cause the current limiters to function. Voltage regulation has been exceptionally good; power continuity has not been interrupted, and to date satisfactory service has been rendered.

An example of how the system protects itself occurred on a Sunday while the whole system was down for adjustment. A total of 1620 kva in capacitors had been distributed in units of 60 kva throughout the plant for power-factor correction. These brought the plant power factor at times of peak loads up to 92 per cent. On the Sunday in question, only one transformer was put into service, and the capacitors were not disconnected. Thus all 1620 kva in

capacitors were connected to one 750-kva transformer. The fuse in the network protector blew, interrupting the load on the system. The workmen had failed to realize the current potentiality of a large bank of capacitors. This serves to indicate that the transformer itself is protected adequately in case of an unusual overload condition.

At a previous time a transformer was connected to the network with the wrong phase sequence. The relay in the network protector did not allow the protector to close, protecting adequately against this type of man failure.

The true test of the flexibility of the secondary-network system came by a sequence of plant changes early in the life of the installation. Before the equipment was placed in service the Nash-Kelvinator Corporation was commissioned to manufacture engine parts for the government in a second plant located in a different section of the city. The projected load totaled 6500 kw. Because the characteristics of the load in the two plants were similar, and because the network system had already been adopted for the first plant and delivery was an important factor, a network system was selected for the second plant. This had the advantage of similar equipment serving as standbys for both plants.



An army beauty for an airman —Hamilton Standard propellers produced by Nash-Kelvinator with the aid of a four-unit secondary network power distribution system.

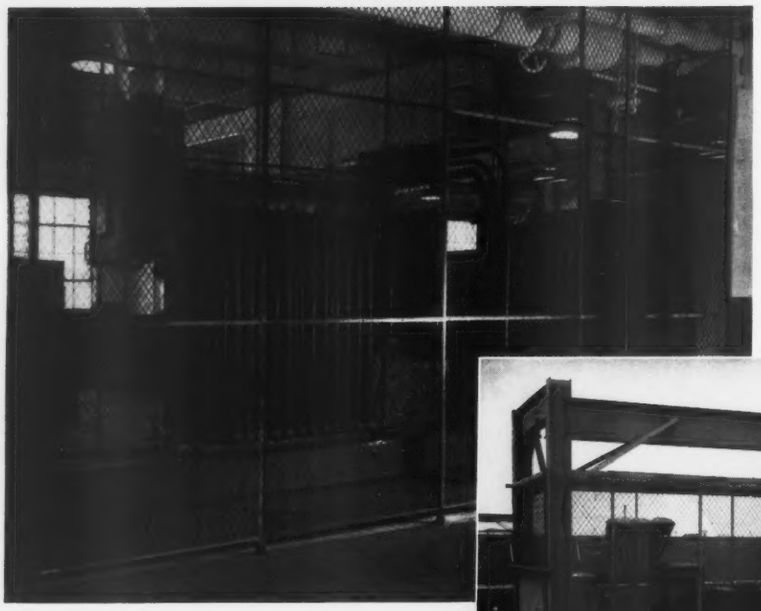
The network plan adopted for the engine-parts plant consisted of three pairs of primary circuits. In general, the plan was similar to that of Plant 1 (Buildings A, B and C), the main exception being that a much longer loop was made necessary because of the shape of the buildings. In Plant 2 the lighting circuits were supplied from the network system, since it was thought that, for this load, the voltage regulation would be satisfactory.

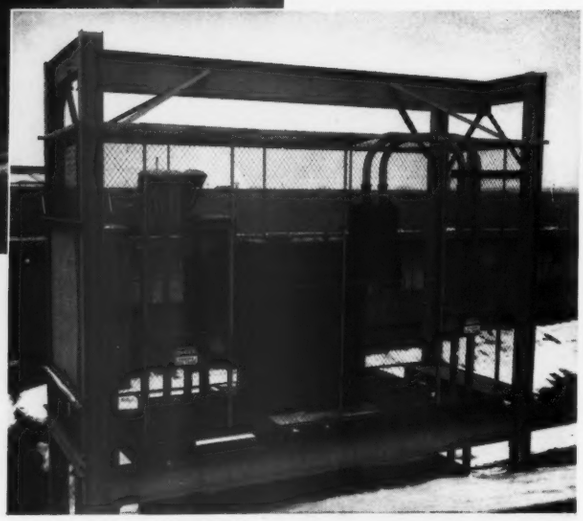
However, before the manufacture of engine parts was begun in Plant 2, a change in the government's requirements and an increased requirement for airplane propellers made it necessary to abandon engine-parts manufacture in Plant 2, and to assign this plant also to the production of propellers, identical to those being made in Plant 1. It was planned at that point to operate both plants for separate, independent manufacture of propellers. The change in the manufacturing operation from engine parts to propellers reduced the load from 6500 to 5200. But this required little basic change in the electrical system. The load redistribution was accommodated readily.

Meanwhile, with the fast-rising tempo of the war, several increases in production were made necessary, and the plant layout changed to absorb them. Still no further radical changes in the electrical system were necessary. Finally, however, production demands became so great that they could not be met by further rearrangement of manufacturing facilities.

It became necessary to change the character of the two plants. The plants were combined into one large plant instead of two individual ones, operating in series instead of parallel, so to speak. By arranging Plant 1 to carry the manufacturing operations on the propellers up to a certain point and then moving them to Plant 2 for finishing and assembly, more efficient use of the facilities could be made, to such an extent that the production demands could be met. The two plants working together could produce more than the sum of their outputs as separate units.

This move, however, entailed major power load changes. The load in Plant 2 was reduced from 5200 to 3300, and the load in Plant 1 increased from 3000 to 4900 kilowatts. It was found that this shift could be met simply by moving two transformers from Plant 2 and installing them on existing limiters in Plant 1. It was also necessary to transfer one primary circuit from Plant 2 to Plant 1. Some rearrangement of transformer loading within Plant 1 was necessitated by the completely reorganized work and machine-tool sequence. Because of a new concentration of ventilation-motor load in one building (Building A of Plant 1), a transformer was moved to the third floor of Building A from the roof of the adjoining building. The method of roof mounting the transformer proved very satisfactory when the move was required. To make a move it was merely necessary to de-energize one primary feeder after the load had been transferred to the others, disconnect the primary lines in to the





An interior transformer installation is shown at the left while the transformer installation on the roof is shown above.

transformer, and disconnect the limiters while energized. This last operation is by no means difficult or dangerous. To reconnect the transformer just the reverse is done. No service interruption resulted from these changeovers.

The expense of these moves was kept low, because practically all the material was available. This was important because materials such as copper and steel were difficult, if not impossible, to obtain. Very little new material was used and that was of a standard type.

Before plans for the general rearrangement of the plant were completed, Westinghouse engineers were asked to check the system of Plant 1 on the calculating board. Although the load taken from the loop was quite unbalanced, the board showed the loading of the transformers to be practically the same. This means that an overload at one spot loads all transformers nearly alike because of the relatively short loop (approximately 1500 feet). These circumstances showed the need for equipment of high current-interrupting capacity. It was found that this was just under 50 000 amperes, just within the capacity of the limiters. The calculating-board survey also indicated that, with the present length of loop, more transformer capacity cannot be installed. However, if this is necessary, a longer loop will be called for, and could be accomplished by cutting an additional tie line in the loop and by placing the additional transformer close to the load, thus paving the way for any further plant increases if necessary.

At Plant 2 a much longer loop existed (approximately 2500 feet). When the two transformers were removed, leaving eight, it was found impractical to reduce the number further because not enough power would be available to cause limiter operation, should a fault occur. We have, therefore, reached our lower power limit there unless the loop is shortened.

Thus in a few months we have changed our manufactured product, increased production and have entirely revamped the plant layout several times. In each case the electrical load was either changed in location or changed in amount and was accomplished with only one major change in the system. This change, although a big one electrically, was not a large one physically and was accomplished with a minimum of expense for labor and material, and with no interruption to the steady flow of propellers needed for our fighting planes.

• • •

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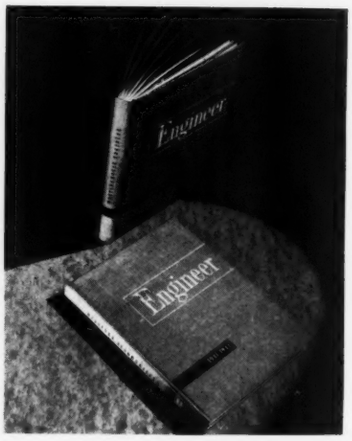


Saturable-Core Reactor Now Smaller, More Capable

The saturable-core reactor was an electrical amplifier of great prowess, performing power-size jobs while the three-element vacuum tube was still but a fragile, weak device. Without fanfare, it has controlled theater lights, mercury-arc-rectifier firing circuits, motor starting, and resistance furnaces and today is being used for many tasks where smooth control of power over wide limits is required. Brought up to date with the newest ideas in core arrangement and Hipersil, the reactor is more useful than ever, lighter and more compact.

E. C. WENTZ
Transformer Engineer, Westinghouse Electric & Mfg. Company

THE idea of saturating the core of a reactor with d-c flux to reduce and control its reactance is an old one. Two familiar forms, commonly referred to as the three-legged and the five-legged reactors, have had many uses, such as smooth control of theatrical-lighting intensity, precision control of the temperature of electric ovens and furnaces, control of the plating current in continuous electrolytic tin-plating mills, control of ignitron firing in applications where heavy currents are needed, and also motor starting.

The saturable reactor can be thought of as similar in action to a three-element vacuum tube. The direct-current winding corresponds to the grid. By variation of a small amount of current in the d-c winding the a-c current output is varied over wide limits and infinitely small steps. A further point of similarity of the reactor and the grid-controlled vacuum tube is the fact that this control entails very small energy loss.

Two forms of construction, shown in Fig. 1(a) and (b), have limitations. Either a great deal of d-c flux is wasted by leakage, or a great deal of relatively idle core (used only to carry d-c flux) is used. Furthermore, the new varieties of grain-oriented electrical core steel (Hipersil) cannot be used to fullest advantage.

As the commonly used sizes of reactor become larger and as wartime material shortages become more acute, some improved form has become desirable. The resulting cores are shown in Fig. 1(c). Two a-c reactors, Fig. 1(d), each consisting of a pair of coils on the cores, are connected in parallel, so that the phase of the a-c flux in one core opposes that of the other to form a duplex or tandem unit. A single coil placed over both cores then has zero voltage induced in it and can be used as the d-c coil. Now the whole core is active, and carries both a-c

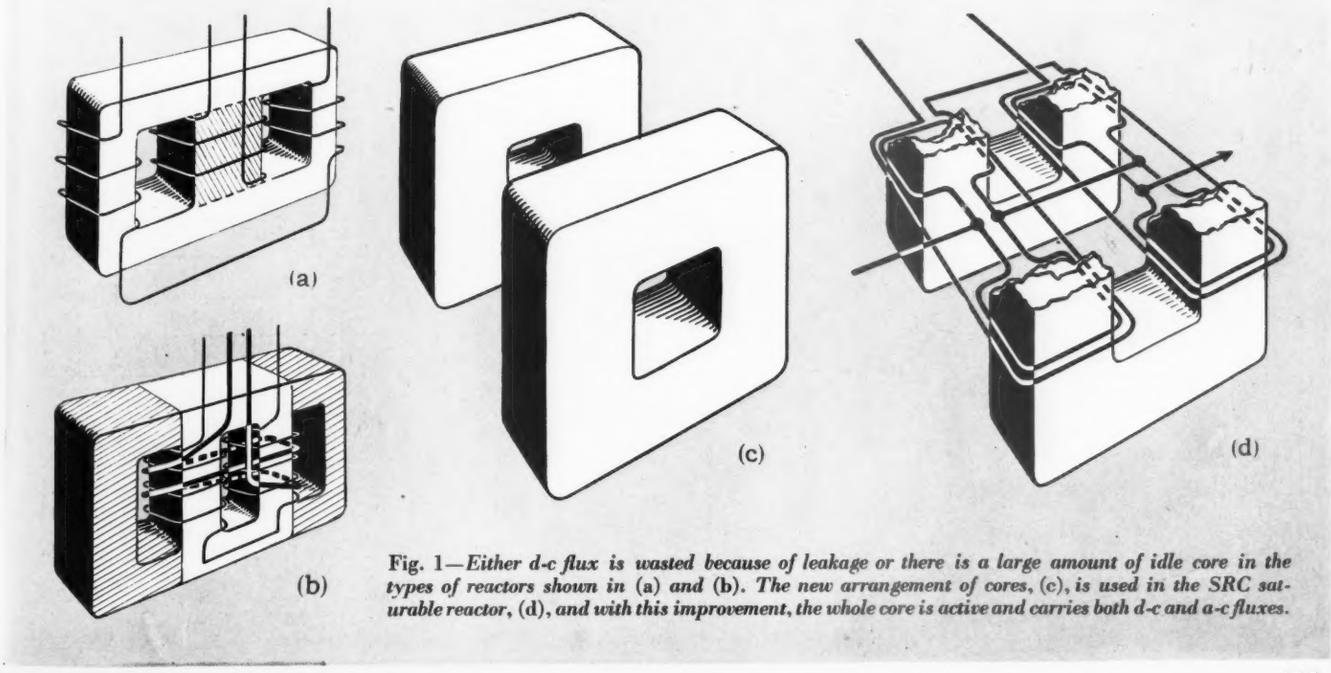


Fig. 1—*Either d-c flux is wasted because of leakage or there is a large amount of idle core in the types of reactors shown in* (a) *and* (b). *The new arrangement of cores,* (c), *is used in the SRC saturable reactor,* (d), *and with this improvement, the whole core is active and carries both d-c and a-c fluxes.*

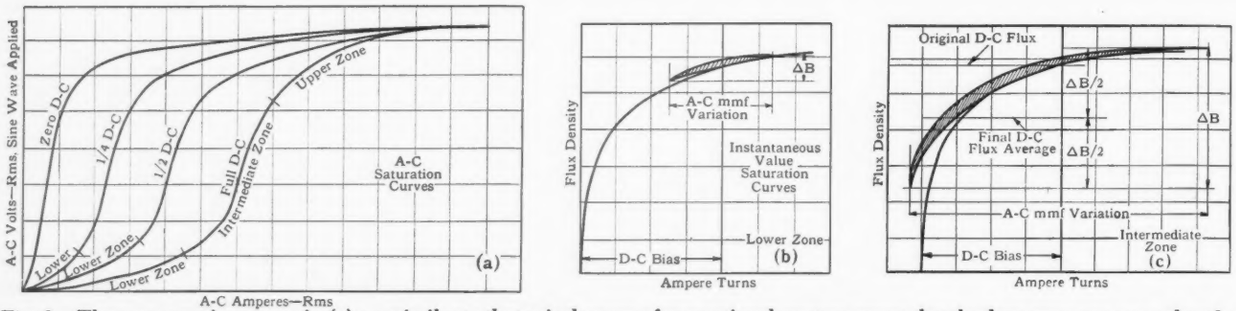


Fig. 2—*The a-c saturation curves in* (a) *are similar to the typical curves of conventional reactors except that the three zones are more sharply defined. The hysteresis loop in* (b) *is typical for the flat, linear lower zone. The hysteresis loop in* (c) *is characteristic for the intermediate zone where the slope of the saturation curve is steep and non-linear and where a small change in current entails a wide fluctuation in voltage. This accentuated dip of the hysteresis loop makes it difficult to compute the precise d-c component of the reactor when in actual use.*

and d-c fluxes without waste through leakage.

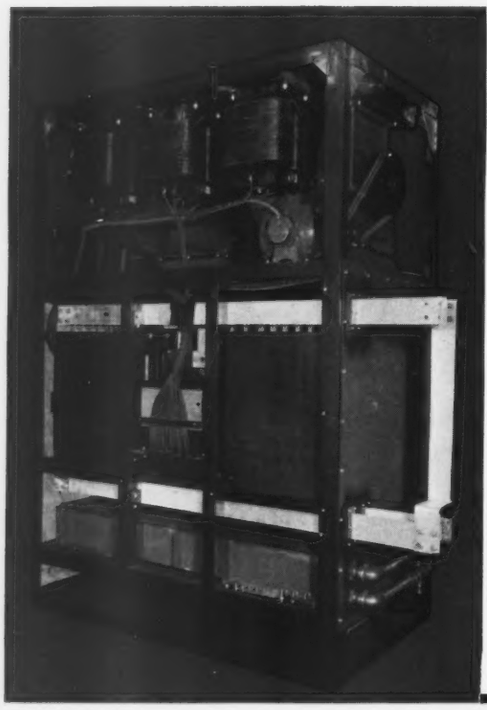
The new construction, known as SRC, does require five coils instead of three. This complication is more than offset by the simplicity of the core construction; furthermore, it is now possible to take advantage of the superior magnetic properties of grain-oriented steel, Hipersil.

The use of Hipersil in saturable reactors carries with it more than the usual advantage attendant with its use in transformers. The extremely low hysteresis loss in Hipersil makes it particularly valuable in a saturable reactor because the core loss is principally hysteresis loss, as a result of the displaced hysteresis loop. In other words, in saturable reactors the eddy-current loss is a relatively small component of the total loss.

The characteristics of this new reactor and the old type of three-legged reactor are generally similar except that the saturation curves are more definitely marked into zones, as shown in Fig. 2. In the lower zone of the curves of Fig. 2(a), the reactor is reasonably linear, because the variation in flux is small and is along the fairly flat upper part of the saturation curve as in Fig. 2(b). As the alternating current and voltage increase into the intermediate zone, the hysteresis loop increases in size, and as it varies around the knee of the saturation curve, the effective reactance changes during the cycle. The reactor is no longer linear as is shown by the hysteresis loop in Fig. 2(c).

If a sine wave of voltage is applied, the current is distorted with large peak values; if a sine wave of current is maintained, large voltage peaks result. This is also shown in Fig. 2(c). As the alternating current increases in the direction opposite to the d-c bias, the flux will increase relatively faster as the left-hand end of the hysteresis loop is reached because of the sharp downward curve at that point. This high rate of change of flux produces a voltage peak.

In the usual application the reactor is in series with a load of constant impedance that is of the same general order of



Three-phase saturable reactors are shown in the top of the rectifier unit at the left. Used for low-voltage current supply in an electrolytic tinning line, each unit delivers 2500 amperes at 12 volts. The output is varied over a ten-to-one range by means of the saturable reactors.

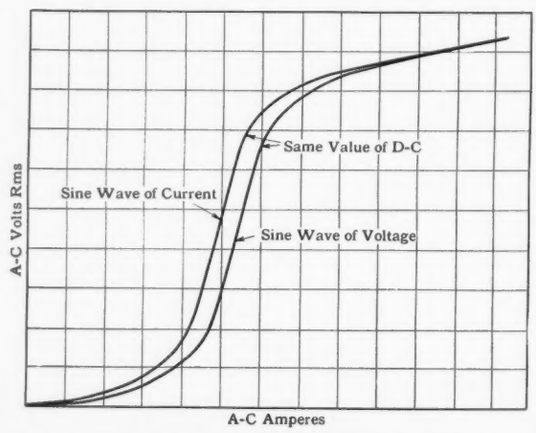


Fig. 3—*At the right are saturation curves resulting from application of a sine wave of current and a sine wave of voltage, the d-c component remaining constant and of such magnitude to cause the reactor to operate in the intermediate zone,* Fig. 2(c). *The fundamental component of voltage is much greater if a sine wave of current is maintained than that if a sine wave of voltage is applied with a comparable rms value of non-sinusoidal current. This makes the calculation of exact load performance difficult from the usual saturation curve measured with sinusoidal applied voltage. This is further explained in* Fig. 2 (c) *by the fact that as alternating current increases in the direction opposite the d-c bias, the flux will increase faster as the left-hand end of the hysteresis loop dips sharply. This high rate of change of flux causes the large voltage peaks.*

magnitude as the reactor impedance. The resulting current when the reactor is in the intermediate zone is a non-sinusoidal current, but the reactor voltage also contains harmonics. The reactor thus generates harmonic voltages that appear across the load, and increase the rms voltage at the load.

When operating in the intermediate zone, Fig. 2(c), the fundamental component of reactor voltage is considerably greater if a sine wave of current is maintained than it is if a sine wave of voltage is applied to the reactor with the same rms value of non-sinusoidal current. This characteristic makes it difficult to calculate the exact load performance of a reactor from the usual saturation curve, which is measured with sinusoidal applied voltage. The discrepancy is generally not too serious, however, as it means simply that the actual direct current required will be only slightly greater than the value calculated from the circuit and the saturation curve. This is borne out in Fig. 3.

The saturable-core reactor can be used in any sort of circuit in which a variable reactor is desired. The factors that limit its use are principally economic. Because the saturable reactor has d-c coils as well as a-c coils it costs about twice as much as a fixed reactor of the same kva rating, and many of its possible applications are not economical. Some of its uses can be discussed as follows:

1—It can be connected in series with a load of approximately constant resistance (100 per cent power factor) to permit adjustment of the current. This is the most common application. The range of control of load voltage is commonly 10 per cent to 90 per cent of the supply voltage. (To go down to 5 per cent or up to 95 per cent is possible, at an additional cost of about 15 per cent.) The reactance in the load circuit should be kept to a minimum. Even as little as 10 per cent reactance in a 100 per cent power-factor load (and this is still 99.5 per cent power factor) means that 10 per cent of the reactor voltage subtracts arithmetically from the load voltage.

2—The reactor can also be connected in series with a load of variable impedance to maintain constant current. The circuit is the same, but this application generally requires an unexpectedly expensive reactor, because the reactor must be built large enough to absorb nearly full-line voltage while at the same time carrying full current.

3—The saturable-core reactor can be connected in shunt as a loading reactor.

4—It is also used as a motor-starting reactor. If the allowable increments of motor-starting current are small, or if the starting current must be closely controlled, a saturable reactor is ideal. The reactor is much smaller and cheaper if it is designed for starting duty only, to be cut out after starting because the winding does not have to carry load current continuously.

Small or large variable reactors can be used for special control applications where no other type of control works as well. This type of reactor can be built in any size from one watt to 5000 kw. Three-phase construction is also practical. The d-c power required is usually about one per cent of the a-c power; the control of large amounts of power is thus simple and not extravagant.

The new type of reactor is built with asbestos-mica-glass (class B, 80°C rise) insulation. The size is still further reduced on this account. The combination of the new type of construction with Hipersil steel and high temperature insulation makes possible a reactor weighing about two-thirds as much with a corresponding saving in critical materials.

LET'S COME TO TERMS

OPTICAL physicists know that the Ångstrom unit (named after A. J. Ångstrom, Swedish physicist) is a measure of minute lengths, and is used when dealing with the wave length of light and of radiant energy close to the visible spectrum. It is an arbitrary unit, one ten-thousandth of a micron (10^{-8} centimeters). It is very close to 0.4 of a millionth of an inch. Industrial, metallurgical, heating, ventilating, and lighting engineers should also get acquainted with the Ångstrom because infrared, ultraviolet, mercury-vapor, and fluorescent lamps have the wave length of their output measured in the cabalistic Å (in Swedish, Ångstrom—literally steam-stream—is pronounced Ōngstrom, long *o*, but in America the Ång is usually pronounced as in angle).

THE WORDS *work* and *power* are loosely used, often even in engineering literature. Certainly they are not interchangeable, but of course anything can happen when technical words are appropriated by lay language. Witness "power of the press" when force of the press would be better. However, the words force, energy, work, and power are tied together in a simple fixed relationship. *Force* is the tendency to overcome resistance and in mechanics is expressed in gravitational units such as pounds. *Work* is the result of force operating through a given distance and hence is measured in foot pounds or equivalent units. *Energy* is the ability to do work and expressed in identical units. *Power* entails the expenditure of energy for a length of time, or foot pounds per second. In a rough way these four units can be thought of as dimensional. Force implies two "dimensions"; energy and work can be considered as having three, effort, direction, and distance; power has a fourth "dimension," time—or effort, direction, distance, and time.

A PHOTOMICROGRAPH is a photograph of an enlarged microscopic object—or is it? Maybe that is a microphotograph. Let's see, the key portion of the two words is micro (from the Greek mikros meaning small). The part of the word modified by micro determines its meaning. Hence, a microphotograph means a microscopically small photograph such as used in Vee mail. It is therefore true that a photomicrograph is a photograph of an enlarged microscopic object taken by attaching a camera to a microscope.

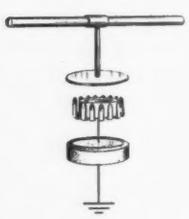
THE WORDS *stress* and *strain* often used together—like spick and span—are not interchangeable. In a general way they can be thought of as cause and effect. Stress is the force per unit area applied to an object; strain is the resulting deformation per unit of length of the object. Thus, stress is the punch; strain is the disturbance it causes. Strains are set up in the members of a bridge by the stresses imposed by passing loads. Stress is measured in terms of pounds per square inch and strain is measured in inches deflection per inch of length.

Lightning Protection for Railway Signal Circuits

Sometimes curtailment in size brings lessened responsibility—but not for lightning arresters. A lightning arrester for signaling circuits must be small, without the large current-discharge capacity of power-circuit arresters, yet it must shoulder the same responsibilities as its bigger brother. In fact, it carries an additional burden. It must in no case become short circuited and cause accidental grounds in the signal circuit, even if badly damaged. It should continue to provide full protection, although damaged, until it can be replaced.

THE signaling system of a railroad is its nerve system. On the signals depend the safety of trains, the orderly and expeditious flow of traffic, and they have important bearing on the amount of traffic that can be handled. Railway signal systems, like other exposed electrical circuits, are subject to damage by lightning, and must be as fully protected as possible. Damage to apparatus or loss of power resulting from lightning surges in the signaling circuits can jeopardize the safe, swift handling of the railroad traffic.

In most respects the protection of signaling equipment from lightning damage is the same as the protection of power apparatus. By-passes, in the form of arresters, must be provided for the lightning currents. At the onset of a surge, the arresters must begin to discharge at voltages sufficiently low to protect the apparatus insulation, and they must allow the lightning currents to pass without dangerous voltage drop. They should be able to handle reasonably high surge currents repeatedly without damage and without changes in their characteristics. They must be used generously, for the protection of equipment at many points; therefore, they should be small and inexpensive. In one important respect the requirements for signal arresters differ from those for power arresters, which are larger and therefore have greater surge-current capacity. Signal arresters should not become short circuited under any conditions.



A new type of low-voltage arrester (RVS) has been developed to meet these particular requirements. Its operating elements are a current-limiting block and a spark gap in series. The principal function of the block, which is of the same construction as the elements in the Autovalve arrester, is to limit the power current that can flow through the arrester gap after the lightning discharge. The series gap keeps the circuit open normally and closes it quickly by sparking when a surge voltage appears. After the surge has passed, the series gap normally interrupts the flow of power current without difficulty because this current is limited by the block. The arrester is thus restored to its insulating condition.

The series gap incorporates two important features. The electrodes are separated by a spacer made of titanium dioxide, a material of very high dielectric constant (approximately 80). This maintains the impulse sparkover voltage at low and consistent values. The other is the gap construction, in which one electrode is a flat plate and the other a circular row of slender points in parallel. The sparking occurs from one of the points to the plate.

Except when the discharge currents are beyond the capacity of the block, the pitting or burning of the electrodes is negligible because the power follow current is limited by the block. Should, however, the block be injured by excessive discharge from any cause, the power current becomes very large, and gap electrodes are damaged. If the gap were to consist of two closely spaced, plane electrodes, such as are sometimes used in low-voltage service, the electrodes might weld together, producing a short circuit. In the case of the pointed gap, melting of the metal lengthens the gap and burns it open instead of closed, thus preventing a short circuit. Should this occur, the arrester does not necessarily lose its

protective ability, because there remain other points in parallel with the damaged one to maintain the low sparkover required for protection of the apparatus. However, the arrester should be replaced at the first opportunity before the damage is extended to all of the points. The RVS arrester is enclosed in transparent plastic so that the internal parts are visible, and damage is indicated by a blackening of the housing.

The combination of Autovalve block and pointed gap provides an arrester with low sparkover, a high discharge capacity, the ability to operate many times without damage, and with a reliable safeguard against short circuit. While it would be a rash statement to assert that no arrester of this construction will ever bridge, the probability of it occurring appears to be negligible. Numerous laboratory tests made under conditions that promote damage have failed to short circuit any of the test specimens. The chance of an arrester of this type bridging is probably less than the risk of other accidental grounds on the circuits.

Arresters generally used for signaling circuits have been of two classes: those that had excellent protective characteristics but might bridge, and those with negligible risk of bridging but with inadequate protective ability or limited life. The new arrester provides a high order of protection with negligible risk of short circuiting.

Although the arrester is intended primarily for the protection of railway signal circuits and apparatus, it can be used for the protection of any low-voltage equipment such as control apparatus or the like that operates at voltages within the rating of the arrester. It is not suited for use on circuits that are exposed to induction from nearby high-voltage lines because these induced voltages cause prolonged discharge that may damage the arrester.

Acme Photo

Single-track operation, particularly in tunneled, mountainous areas, demands the utmost in lightning protection with safety.

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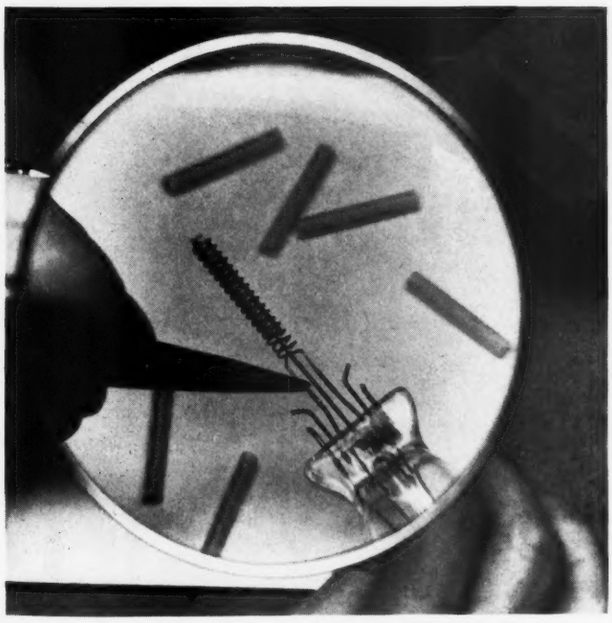


Spaghetti á la Bloomfield

CHALK up an assist by the Axis in our production-for-war effort. To add to their chagrin, the assist was to remove a bottleneck in the production of the all-important electronic tubes, a vital factor in the Allied success in the field. Through the use of bits of spaghetti, the Italians' national dish, the time required to assemble certain tube elements has been reduced 75 per cent and the need for split-steel forms eliminated.

The electron-emitting filaments of many types of tubes are wound in the shape of a small spring some three-quarters of an inch long. The plate, grid, and emitter elements in an electronic tube must be accurately aligned and welded in position so that the relative positions are uniform to give identical operating characteristics to all tubes of a given type. To hold the coiled filament in position, a core of steel was inserted to hold it rigid during the welding operation. Despite the fact that this mandrel was split to facilitate its removal, it often became stuck and distorted the filament during removal.

In keeping with the war economy the new recipe is simple. Take one piece of raw spaghetti. Insert the spaghetti in the filament to hold the coils rigidly in place during assembly of the tube components. After the assembly is completed, pass the usual current through the filament to drive off the impurities. This burns up the spaghetti in a flash. The mandrel-removal problem disappears in a puff of smoke. A tasty dish, but not for the Axis.

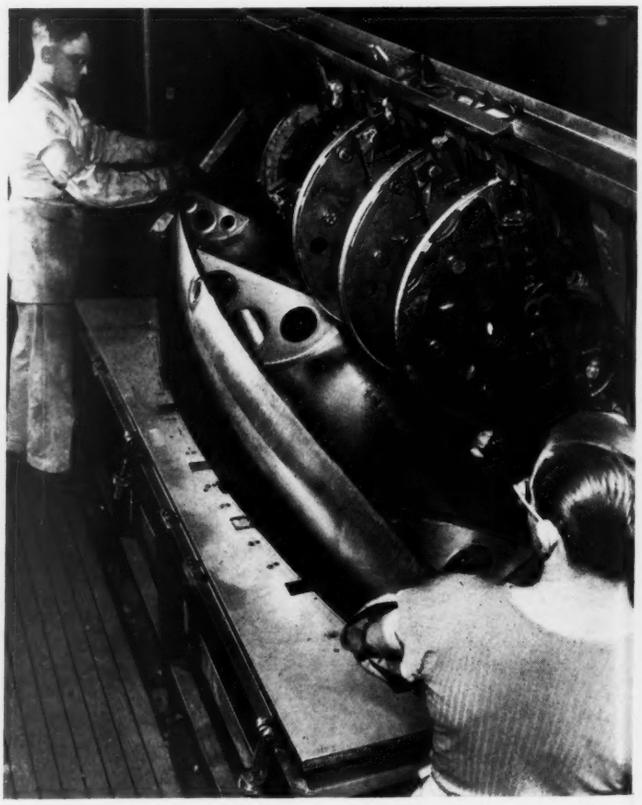
Drop-Type Gas Tanks via Electronics

IN MODERN, global warfare, planes must travel great distances to engage the enemy. Planes designed for large gasoline loads are at a disadvantage when fighting. In order to increase the effective range of the P-38 pursuit ships, the outbound trip is made on gas carried in two tanks slung from the under side of the wings. When the auxiliary gasoline supply is exhausted, or when combat is joined, the pilot can immediately jettison the tanks.

To produce the required large quantities of light, strong, streamlined gasoline tanks, Lockheed's engineers combined the latest in welding techniques with mass production methods. Today, completed tanks flow off the continuously moving conveyor line at the rate of one every four and a half minutes or more than three hundred a day.

The tanks were originally made of aluminum, but material shortages caused a swing to mild sheet steel. The tanks are formed in large presses similar to those commonly associated with automobile-body manufacturing. These presses form the flat sheet metal into two half-sections that are later welded together to form the long tear-drop tank.

The sheet steel, being only about 1/64 inch thick, is as flexible as heavy paper. It is necessary to incorporate stiffening metal bulkheads, which act as both cross braces and hanger supports. These are spot welded into place in two special welding fixtures that serve the dual purpose of welding machines and a jig for positioning the bulkheads. Each machine makes a complete half section of the tank in one operation. The bottom portion of these welding jigs contains copper-alloy electrode bars machined to fit exactly the outside contour of the pressed steel-tank section. These



This ingenious fixture developed by Lockheed welds four bulkheads in place simultaneously. Bulkheads are positioned by the jigs in the hinged cover and are welded by roller spot welders on arms that are pivoted on the longitudinal axis of the tank.

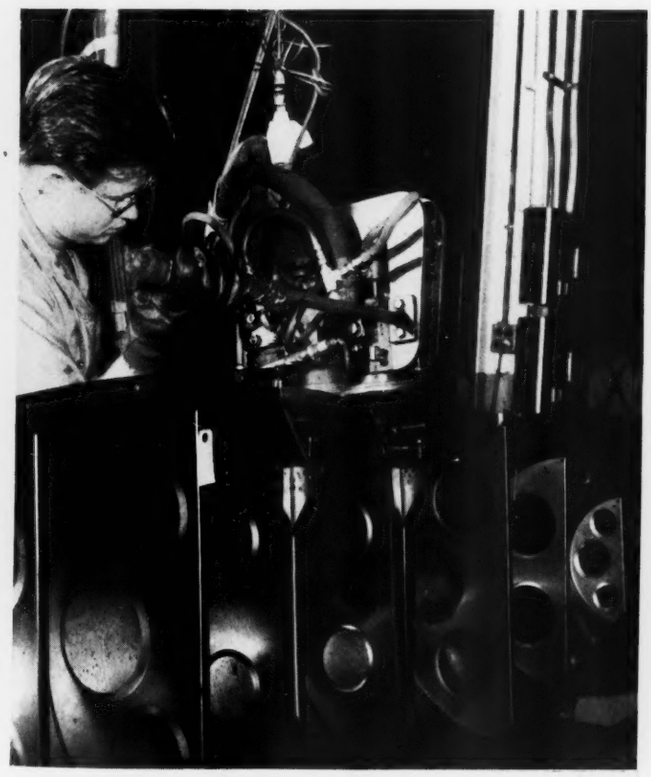
heavy alloy bars form a contact with the tank surface for the welding operations. The top frame of each fixture holds specially designed welding arms that swing on a longitudinal axis. Each of these arms is equipped with a hydraulic cylinder and a copper roller head that rolls along the inside surface of the tank, making spot welds at predetermined intervals. A geared driving motor swings the arm through 180 degrees, traversing the entire semi-circular surface of the tank section. Each bulkhead position is equipped with a welding arm, and when the bulkheads are positioned in the tank, they are all welded simultaneously. The welding requires one minute for each of the two machines and the loading and unloading operations each requires one minute.

The two half-sections of a tank are joined by a continuous seam weld running completely around the outside of the tank. This is performed on a standard seam welder. The excess of the projecting fin is trimmed in a stamping operation. Supporting hangers, that are used to attach the tanks to the under-wing surface, are spot welded in place by means of portable gun welders and a unique Lockheed-designed portable seam welder.

Each seam-welding head receives its electrical power from a separately mounted transformer which is controlled by Westinghouse ignitrons and a welding timer. Each of the seven welding arms in the fixtures is so equipped, permitting individual adjustments. In addition, there are three portable gun welders with their transformers and Weld-o-trol and timers. A Westinghouse combination spot, seam, and pulsation timer controls the seam welder that joins the two half-sections. These electronically operated controls are located as much as 150 feet from the work centers.

One of the electronic units which precisely controls the various intricate operations of the welding devices used in making tanks. These units are located as much as 150 feet from the work center.

The two halves of the drop-type tank are welded together with a seam welder in the final assembly, producing a leakproof, rivetless, disposable gasoline tank of great strength and 165-gallon capacity.



The hanger assembly, which is engaged by a clamping device in the wing section, is attached to the tank by a portable seam welder.

Stories of Research

Resistance-Welding Current Indicator*

INSTRUMENTS are projected eyes whereby it is possible to see within mechanical and electrical apparatus and determine accurately what is taking place. Such a seeing aid, which has long been needed, is the apparatus recently developed by A. B. White, of the Westinghouse Research Laboratories, for more exact measurement of the rms current of resistance welders.

Each welding operation demands certain specific characteristics depending upon the type and size of the welded materials. Among the several variables that must be strictly controlled to insure sound welds are the amount and duration of current applied to the weld.

Resistance-welding current flows from a fraction of a half cycle to a second or more. The brevity of the flow makes ordinary current-reading instruments unsatisfactory for this application, as the instrument movement is unable to reach its steady-state position before the current has ceased flowing. Also, the accuracy of conventional instruments is affected by the harmonics introduced by heat-control apparatus which controls the current by reducing the duration of flow in each half cycle of the supply voltage wave.

This new current-measuring instrument is a balanced potentiometer bridge circuit with the reference voltage derived from the instrument input current. A pick-up, through-type current transformer is mounted on the electrode holder or the horn of the welding machine to provide this operating current for the current indicator. For any given value of current input, the potentiometer contact is adjusted to obtain balance. Balance is indicated by a zero reading on the galvanometer. The potentiometer dial is calibrated directly in amperes either for current at the input terminals or for the welding current passing through the pick-up current transformer. Because the reference voltage is supplied only when the current being measured is flowing, the galvanometer does not deflect when the potentiometer is balanced for that particular current value, nor does it deflect when the current input is zero.

However, any deviation of the current value from that for which the instrument is balanced will cause a deflection of the galvanometer. Inertia effects of the meter are, therefore, eliminated, and the operation of the instrument is inherently independent of the number of half cycles in which the current flows.

When the wave shape of the welding current is changed by heat-control equipment, the ratio between the average value and the effective value of the current is also changed. The circuit balances average values at the galvanometer so that some measure of compensation must be effected. In a distorted wave form usually resulting from resistance welder heat controls, the amplitude is greater, but the time of current flow in each half cycle is shorter, so that the time rate of change of the distorted wave is greater. Based on these facts, a compensating device is included in the current indicator which permits calibration of the instrument in effective current. This operation holds true for resistance welders exclusive of flash and stored-energy welders, which present individually unique problems in current measurement.

*Note: The resistance-welding current indicator described in this article is purely a research development and is not a commercially available manufactured instrument.

Mr. White has adjusted the current indicator to a zero reading on the galvanometer. The figure on the dial is easily converted to amperes by reference to a chart. Note the pick-up coil placed over the lower electrode. This shows the ease of applying the current-measuring instrument to a welder.

Stress Distribution Determination

THE ORIGINS of the wheel and also of gears are lost in antiquity. Since the era when wheels and gears were made of wood and stone, the wheel has been pretty well explored. But there are many complex problems in gearing which leave a desire for further investigations. With the aid of a new tool called Stresscoat, further explanations are made possible and will permit exploration of such problems as the determination of stress set up by diagonal loading of spur-gear teeth and other abstruse questions that have been beyond the limits of mathematical calculation because of the number of unknowns involved.

Stresscoat is a lacquer preparation that is applied to the surface of the material to be subjected to stress and evidences this stress by minute cracks that appear in the lacquer. These cracks appear uniformly spaced for each multiple of a characteristic strain in inches per inch and are always normal to the direction of the stress applied. A test bar having the same modulus of elasticity as the part under test is coated with the lacquer. A lever and cam arrangement stresses the test piece and the first crack that appears in its lacquer coating is easily calibrated on a convenient strain scale in inches per inch. This measure of strain is uniform within the elastic limits of both the material under test and the calibrating test piece so that not only can the direction of the strain be determined, but also a close determination of its magnitude.

Work is now under way in determining the location and magnitude of the strains set up in the filet of a gear tooth having a loading on the

In the picture above, a universal testing machine with a capacity of 400 000 pounds is used to place a load on a gear tooth, diagonal to its axis. To insure uniform loading, two spur-gear teeth were machined on opposite sides of a 1600-pound casting and both teeth loaded equally. The strains set up in the filet by this loading are shown in the photograph to the left by the fine diagonal cracks that were produced in the Stresscoat lacquer film covering this filet area.

face of the tooth diagonal to its axis. To this end, spur-gear teeth were machined on opposite sides of a block of steel and were made entirely proportional but many times normal size for ease of manipulation and interpolation of the test. The two teeth were used to equalize the loading in the universal testing machine.

By such investigations as conducted in the Westinghouse Research Laboratories, the knowledge of gear fundamentals, which have been obscured in past ages, will be brought to light and will result in better, less cumbersome design.

Research scientists are aided in another avenue of investigation by this lacquer. Static loading has been known, appraised and tested for a long time. Impact or dynamic loading has been something of a mystery through inability of correctly assessing the extent and direction of the strain in a plate under a given impact and hence an inability to place strain gauges properly for the measurement of strains set up. These would still not give the stress distribution of an impact. Such a distribution is very graphically given by Stresscoat, and if both the front and reverse of a plate are coated widely divergent patterns on the two will appear as a result of the impact. This development has many possible wartime applications and should be an effective tool for peacetime activities.

Exploring Electron Emission

INTENSIVE research begun in the days of the Edison Effect, the Fleming Valve, and the deForest Audion is now beginning to bear fruit. It is only natural that the fundamental laws of electronic phenomena should be considered so important. Scarcely a field of industrial activity has remained untouched by the rapidly growing and revolutionizing electronic art. The reliability and sensitivity of electronic devices are proving the extent of the knowledge of electron characteristics accumulated in past years. And now an increasing knowledge of the fundamental principles governing the emission of electrons begins to emerge as a result of the more than eight years of research on this subject by Dr. H. C. Rentschler and Mr. D. E. Henry, of the Westinghouse Research Laboratories.

It has long been known there existed in metals a greater or lesser number of free electrons, the number being a characteristic of the metal involved. The tenacity with which these free electrons are held within the confines of the metal is also an individual characteristic, some metals giving off electrons freely and others only with difficulty.

In most metals the energy inherent in the free electron is insufficient to enable it to overcome the bonds that tie it to the parent metal. It is

necessary, therefore, to supply such additional energy that these bonds can be overcome. This is done by heat for thermionic emission and photons of light in the case of photoelectric emission. A positive field is established in most electronic devices to accelerate the speed of the electrons, once clear of the emitter, in the desired direction to prevent their return to the parent metal. The amount of energy required to overcome the attraction of the electrons for the metal, and to cause actual emission, is called the work function of that metal for the conditions surrounding the experiment.

Early emitters, especially in radio tubes, required considerable expenditure of energy to free an adequate flow of electrons. Research developed the various oxide coatings with lower work function to provide devices whose power demands were comparatively limited. In applications where high plate voltage or relatively high power, or both, is essential, it is found that the oxide coating is literally ripped off by the strength of the field. Dr. Rentschler several years ago undertook the investigation of the electronic properties of metals in which oxygen had been dissolved much as carbon enters into solid solution in steel.

Oxygen is dissolved in a number of metals, some usually associated with electron emission, others not. It is now known that oxygen entering into solid solution disturbed the crystal lattice of the metal and this weakened the bonds of the atom for the "free" electrons. This weakening of the atomic bonds made itself manifest by a lowering of the work function in the case of the metals whose emission of electrons takes place through the use of heat energy. In the case of the light-sensitive metals, from which electrons are emitted by the energy released through the impact of light photons, there has been a corresponding lowering of the work function. This has been demonstrated by the latter metals showing a longer wave length (lower frequency) photoelectric threshold. The photoelectric threshold is the longest wave length of light for which electrons are emitted.

Dr. Rentschler exploring emission phenomena.

Metals that have undergone test after entering into solid solution with oxygen and that have responded with an accelerated electron emission include hafnium, thorium, titanium, zirconium, and barium. Iron, copper, and nickel, however, showed no such effects.

This solving of one of the riddles of physics by research has exciting possibilities of a practical nature. Lowering the work function means as much or more electron emission with less filament input. Further, with oxygen a component part of the metallic filament surface, rather than in an oxide coating, the accelerated electron emission of such a solid solution may soon be available for power-tube application where before the use of an oxide coating proved impracticable.

Some 56 miles of thermostat wire, enough for 20 000 bombers, being born in a shower of sparks.

USING a process that was ancient when the pyramids were being built, Mr. P. R. Kalischer of the Research Laboratories is making iron cores for control magnets used in circuit breakers. The fundamental principles of powder metallurgy are that old. He presses the powder into a previously machined die and then sinters the resulting metal core piece in a hydrogen atmosphere. These pieces are accurate to one thousandth of an inch, have true corners, polished faces and need no machining. For this U shape, powder metallurgy is faster, cheaper and has less scrap loss than usual machining processes.

Kovar

USE OF research-developed products often makes strange bed-fellows. The alloy, Kovar, originally developed at the Westinghouse Research Laboratories for use as a metal in the stem seal of electronic tubes, is now riding high over battle lines as a part of bombers. Because its ohmic resistance varies greatly with temperature, instrument manufacturers find it ideal for use in constant-reading electrical-indicating thermostats. War demands for such thermostats, used for registering engine-oil temperature in plane motors, etc., swiftly depleted the manufacturers' supply of this special alloy. Kovar with the required heat-resistance gradient is not now available on the market. Research engineers worked for weeks to duplicate the original supply. They reproduced a metallurgically exact alloy with the same electrical characteristics. It is now produced in small 13-pound ingots in laboratory electric furnaces. There is enough Kovar in each ingot to make 56 miles of thermostat wire, ample for some 20 000 four-motored bombers. Actual production of material is ordinarily outside the province of a research laboratory, but this, like many other unwonted activities, is taken in the war-effort stride.

Luminous Bacteria Aid Cross-Infection Tests

IN VIEW of the staggering number of man-hours lost through the common cold and other similar diseases, the importance of the prevention of cross infection in homes, offices, and war plants cannot be over-emphasized. These infections are carried by air-borne bacteria or virus. Ultraviolet rays have proved successful in liquidating these organisms and investigations have been furthered by Dr. Harvey C. Rentschler, of the Westinghouse Research Laboratories, to determine the best methods for applying these air-sanitizing rays.

The Sterilamp emits ultraviolet rays lethal to bacteria and virus. To determine the most effective placement of these lamps, tests were conducted in a laboratory where conditions were completely controlled to find accurately the distribution of germs sprayed into the air, simulating the action of a sneeze. The distribution was established by means of Petri plates which were placed about the laboratory. Germs striking these culture plates were incubated for a stated period and counted.

In the laboratory, there was no possibility that the Petri plates could be contaminated by outside germs. In an actual office under normal conditions, no such germ control is possible. It was necessary then to utilize harmless bacteria readily recognized and palpably distinct from other air-borne bacteria usual to an office.

Vibrio phosphorescens is distinctive because its culture is luminous. These bacteria, sprayed in the air, and collected at various places, gave a true picture of the way they diffused to other places in the room. The Sterilamps were placed at the strategic positions determined by laboratory experiments. It was established—using luminous bacteria—that cross infection can be prevented. A room can be isolated, or different areas of the same room can be segregated by the invisible rays so that no infectious organisms can readily pass from one to another.

Bacteria-free conditions possible in a laboratory cannot be attained in an office or room. An easily identifiable bacterial form is necessary to check laboratory findings in normal surroundings. The luminous bacteria shown in the inserts solved the problem.

High-Frequency Pilot Arc for Alternating-Current Aircraft Welding

ALTERNATING-CURRENT welding proved itself some six times faster than previous methods of assembling motor frames, landing struts, etc., but it had two serious deficiencies when using low current and small rods on light gauge metal: the operator experienced difficulty in striking the arc, especially in alloy welding, and often lost the arc during a weld. A weld is never as good if the arc has to be restruck and the weld continued. This difficulty was overcome by superimposing a high-frequency voltage on the low-voltage, high-current welding arc.

Using alloy rods such as are common in the aviation industry, even high-current arc welding can be difficult with regard to arc striking and losing the arc. This is particularly true of low-current welding using alloy rods. These two difficulties both stem from the same cause, inability of the electrodes to maintain sufficient ionization under manual welding conditions to continue the arc through current zero.

Early in the development of a-c welding it was suggested that a high-frequency, high-voltage current be imposed on the welding arc to cross the gap and cause sufficient ionization to maintain the welding arc or permit its instantaneous reestablishment without restriking. Two problems inherent in this scheme had to be overcome. A spark oscillator provided the most practical source of high-frequency ionizing current, but this type of oscillator produces insupportable radio interference. A completely shielded, double-tuned spark oscillator was designed with the tuned circuits inductively coupled, which eliminates or minimizes radio interference caused by sporadic and harmonic oscillations in the broad cast range.

Secondly, despite the addition of this improved source of high-frequency ionization current, the arc was still difficult to strike at times and sometimes was lost during a weld. Between each train of highly damped oscillations is a very small interval. If this interval happens to coincide with the zero point of the welding-current wave, the arc again may fail to re-strike. A phasing control neatly solved this problem by making the current zero of the welding arc and the high-frequency train of the pilot arc coincidental. This improved phase relationship between the two always provides nearly maximum voltage of the pilot arc when the welding current is zero and in this manner maintains the arc despite poorly stabilized electrodes, line-voltage fluctuations, and other causes of losing the welding arc.

The Westinghouse high-frequency-stabilized a-c aircraft welder was designed around specifications peculiar to this industry. The transformer is of the movable-core type, giving stepless current control throughout the welding-current range from 10 to 200 amperes. The welder is provided with a calibrated preset current indicator. However, the current setting can be adjusted during operation, if desired. A switch in the handle of the rod holder controls the high-frequency current, starting the stabilizing arc with but slight finger pressure. The unit is light weight and easily movable on the two wheels and caster provided.

The speed of welding thin-gauge tubular parts for aircraft has been greatly enhanced through the use of the stabilized a-c arc. Striking and retaining the arc when using low current and small rods is no longer a major problem, using the high-frequency arc.

Damping Oscillations in Welding Capacitors

This newly designed self-protecting capacitor has built-in distributed resistance to absorb the high-frequency voltage oscillations resulting from operation with stored-energy welders, particularly those oscillations arising from capacitor switching for different welding currents.

THE increased use of light alloys with their critical point-of-flow temperature has increased the use of the energy-storage type of welder. These welders utilize the energy stored in a bank of capacitors to apply the precise amount of energy to the weld point to complete the weld and still not fuse the processed material all the way through. In energy-storage welding the aperiodic nature of the discharge and freedom from oscillations makes possible a design of capacitor with high working stresses and a minimum of insulation, which makes for economy. To insure oscillation-free discharges, it is necessary to keep the series resistance of each capacitor unit above a minimum value for a given capacitor rating.

In practical applications the damaging oscillations arise from two principal sources. In the first, the complete circuit must be considered as a whole and the constants of the circuit so designed and regulated that oscillations are avoided.

Voltage oscillations also result when charged capacitors are connected to uncharged capacitors. In each welding operation the current needed varies with the size, shape, and type of material. These variations of welding current in the energy-storage welder are usually achieved by connecting or disconnecting capacitors to vary the total microfarad capacity to suit the different welding conditions.

It has been customary to use externally mounted resistances connected in series with the capacitors to prevent voltage reversals arising from switching operations during which charged capacitors are connected to uncharged capacitors. The discharge of the conventional condenser, i.e., without series resistance, is shown in Fig. 1. This is relatively undamped and would be hazardous to capacitors built to operate at high working stresses. The conventional method of suppressing these oscillations is to mount resistors on top of the capacitors. This entails a substantial increase in the mounting space for a bank of capacitors and also increased cost because the resistors must be of adequate size and rating to dissipate the heat. This is especially true where the duty cycle is heavy and the number of welds per minute is high.

Both of these causes of voltage oscillation have required the addition of external resistances. It would be desirable to eliminate these resistances in the interest of economy of space and simplicity, and this has been accomplished by a new self-protecting capacitor in which the internal resistance has been made intentionally higher by a special arrangement of the foil and the method of connecting the capacitor components. Thus, a 120-microfarad capacitor with a 3000-volt rating has the equivalent series resistance of 0.125 ohm built into it. The resistance of a standard unit is but 0.007 ohm. This is accomplished without any additional material. Because the heat generated in this resistance is distributed throughout the entire mass of the capacitor, it is dissipated within the capacitor without creation of hot spots.

The characteristics of a discharge of a self-protected capacitor are shown in Fig. 1(b). This capacitor is of the same capacity and rating as the capacitor used in producing the oscillogram in Fig. 1(a), and the circumstances of the charge and discharge were identical. The wave form of the damped discharge of the new capacitor obviously satisfies the two main conditions for continuous, trouble-free operation of a stored-energy capacitor; it eliminates abuse and breakdown of the capacitor because of oscillatory stress arising from the normal operation of the welder and protects the capacitor from the violent, high-frequency stresses occasioned when a charged bank of capacitors is connected to an uncharged bank.

A further advantage of the internal resistance construction is of particular value because of the close placement of units in a bank of capacitors for a stored-energy welder. If an insulation failure does occur, a tremendous amount of energy is fed into this fault from the other capacitors. This may be sufficient to rupture the case of the capacitor that failed and communicate damage to adjoining capacitors. The integral resistance of the self-protecting capacitors acts as current-limiting resistance under fault conditions and inhibits the violent flow of energy into the fault and prevents physical demonstration that might damage the adjoining capacitors.

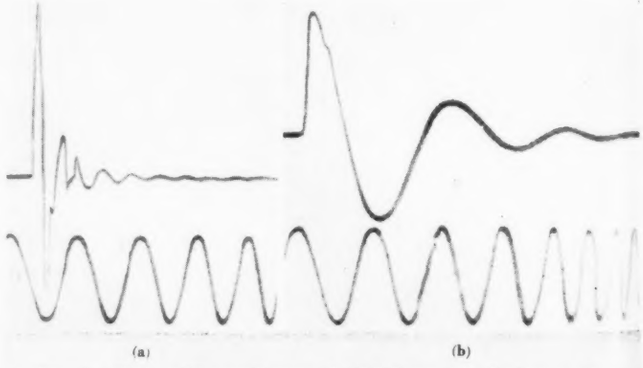


Fig. 1—*The oscillograph trace in (a) shows the discharge of a conventional capacitor to be a high-frequency oscillation. The discharge of the self-protecting capacitor, (b), shows the damping effect of the internal resistance. The timing trace represents 10 000 cycles per second. The discharge currents in the two traces vary widely. The deflection calibration of the oscillograph trace (a) is 24 500 amperes per inch and (b), 1260 amperes per inch.*

The Mass Spectrometer for Gas Analysis

Yesterday's scientific instruments become the tools of industry today. The mass spectrometer, long a laboratory device for fundamental physical research, is being lifted to the high-octane gas and synthetic-rubber production lines. Combining this purely physicist's instrument to the chemist's needs results in closer supervision of production processes and better war-needed products, quicker.

THE suddenly developed need for high-quality aviation gasoline, synthetic rubber, explosives, and other important materials having a vital relation to the success of the war effort gave impetus to the task of finding improved means for quickly and accurately determining the purity of constituents forming a part of these products. For making these determinations such methods as pressure distillation, solvent extraction, fractional crystallization, infra-red and ultraviolet absorption, and others of less importance, have been employed with varying degrees of success. But all possessed shortcomings of one type or another that accelerated the search for new analytical instruments, particularly one that would facilitate making analyses of complex hydrocarbon mixtures. Such an instrument is the mass spectrometer.

The mass spectrometer, as the name implies, is an instrument in which ion streams of different masses can be separated and measured in a manner that permits both qualitative and quantitative measurement of the components of a gas mixture. It is essentially a high vacuum tube into which this gas to be analyzed is admitted and ionized. By closely controlled electrical and magnetic fields, the ions are caused to move through the tube so that each stream of ions of different mass can be successively focused on an exit slit at the end of the tube where they impinge upon a plate and give up their charge. This charge or current is amplified and measured by electrical instruments. From the characteristics of these electrical readings the exact composition of the gas mixture is readily obtainable.

Operating the mass spectrometer involves the synchronizing of many precise components.

The vacuum tube with ionization chamber and the magnetic pole pieces are shown in detail in Fig. 1. A schematic drawing of the mass spectrometer together with the more important components is shown in Fig. 2(a). The gas to be analyzed is pumped through the ionization chamber through the zone where the electron beam is defined and is ionized by the impact of the electrons on the gas molecules. The ions thus formed just below electrode 4 are driven by a small potential difference between 4 and 2, Fig. 2(b), through the long slit in electrode 2, forming an ion beam. This ion beam is then accelerated by a much larger potential difference between 2 and 5, the latter being at ground potential. Passing through the slit in 5, the narrowly collimated beam enters the analyzer region of the tube which has a grounded metallic shield on the inner surface.

Thus far the beam contains all the ions formed by the electron beam bombarding the gas mixture in the ionization region. Ion separation begins at the point where the ion beam enters the region between the pole pieces of the electromagnet. As the magnetic field in this gap is perpendicular to the direction of the motion of the ions, the ions are bent in circular paths—all ions of any given mass (assuming all ions singly charged) receive the same deflection but different masses obviously have different radii of curvature. The lighter the ion mass the smaller will be the radius of curvature of its path. If the accelerating potential and the magnetic field are adjusted so that the ions of a particular mass are focused on the exit slit, lighter ones strike the tube on the upper side of the main ion stream and heavier ones on the lower side, where both are drained to ground. By adjusting the magnetic field or the accelerating potential, or both, the ion streams of different masses can be

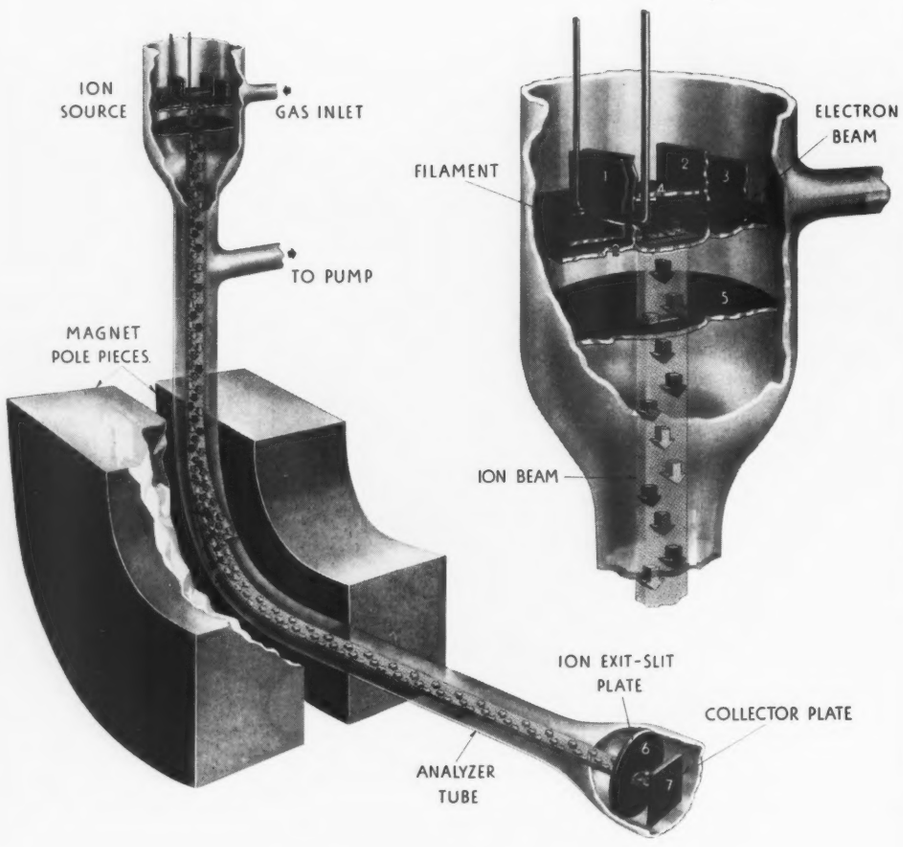


Fig. 1—*The operation of the mass spectrometer tube is shown in this idealized view. The manner in which the horizontal electron beam originates in the filament at the left is shown in detail in the enlarged view of the ion source, upper right. The ion beam is projected into the tube and deflected by the magnetic field. The separation of the ions of different masses is indicated by the variance in the radius of curvature of the gray- and black-arrow beams in the area of the magnetic field.*

successively focused to pass through the exit slit of the tube and impinge upon a collecting electrode where their charge is given up. The current reaching this electrode is amplified and measured; its magnitude in each case being a measure of the number of molecules of this species in the mixture.

A typical analysis to determine the amount of oxygen and nitrogen in that common gas mixture, air, illustrates the functioning of the apparatus. First a blend of oxygen and nitrogen of any convenient but carefully measured proportions is prepared and allowed to flow through the mass spectrometer tube as indicated schematically in Fig. 2. This blend of nitrogen and oxygen is used as a standard. Ions of both nitrogen and oxygen emerge from the ionization chamber into the analyzer. The fields are adjusted so that mass 28 (nitrogen) is focused on the exit slit of the mass spectrometer and the current measured. Mass 32 (oxygen) being heavier is not deflected as much by the magnetic field and is lost on the grounded interior of the analyzer. The fields are then readjusted so that the current corresponding to mass 32 may pass through the exit slit and be measured. The nitrogen ions are obviously deflected more (have a shorter radius of curvature) and are lost on the grounded shield. The instrument is now calibrated for nitrogen and oxygen in any proportions, and if air is allowed to pass through the mass spectrometer we can quantitatively determine the composition from the current readings obtained when the conditions have been set so that nitrogen ions and oxygen ions produce successive readings. In other words the patterns of the unknown mixture are compared with the known standards.

There may be some question about the extension of these calibrations to mixtures in which the relative proportions of constituents are far removed from that for which the calibration was made. It should be appreciated that the ion current corresponding to a particular substance in a mixture varies directly as the partial pressure of that substance in the mixture. The mean free paths (the average distance which one molecule traverses before striking another molecule) of both electrons and ions are long compared with the dimensions of the apparatus. Thus, the probability of interaction between molecules or of multiple collisions by an electron are small, because the gas to be analyzed flows through the instrument continuously during the analysis and the pressure within the system is of the order of one ten-millionth of an atmosphere.

The spectrometer can work on very small amounts of gas, an important condition where samples for analysis must be sent to a central laboratory remote from the point of origin. The gas-handling system is arranged so that there is a continuous flow of gas through the tube at all times, but this flow is only of the order of one ten-thousandth cubic centimeter per minute at atmospheric pressure.

The electron current in the beam responsible for the gas ionization is in the order of 10 microamperes (one one-hundred-thousandth of an ampere). The ion current emerging from the exit slit is between one ten-thousandth and one billionth of a microampere (a microampere is one millionth of an ampere) depending upon the mixture being analyzed. The current in the antenna of an ordinary radio receiving set is about one microampere. When it is realized the currents that must be amplified and recorded in the mass spectrometer may be one billionth of this, some conception is had of the degree of sensitivity of the instrument in detecting minute quantities of any substance in a mixture. It is of

interest that as little as one part of oxygen in ten thousand parts of nitrogen has been detected and this is not the limit of the sensitivity of the instrument.

In a typical instrument the radius of curvature of the ion beam is between ten and fifteen centimeters. The ion accelerating voltage is approximately 1000 volts, d-c, and the electron accelerating voltage is less than 100 volts, d-c.

The spectrometer, which consumes about 15 kw, operates from any 110-volt, 60-cycle alternating-current source. An a-c voltage regulator is used to stabilize the line voltage. The power packs supplying direct current for energizing the magnet and for accelerating the ions are vacuum-tube regulated and these particular voltages are held constant to one part in ten thousand.

Accuracy of the instrument is affected by humidity and temperature but special precautions to maintain these factors fairly uniform are necessary only in regions where high humidity (above 50 to 60 per cent) is encountered. Under such climatic conditions or where extremely accurate laboratory work is required, an air-conditioned room is desirable.

In discussing the applications of the mass spectrometer it should first be appreciated that most of the problems of interest today are not as simple as the example of oxygen and nitrogen used above for illustration. Even in that example there were other masses present that were not mentioned. There are two isotopes (elements having the same chemical properties but different atomic weights) of nitrogen, N^{14} (mass 14) and N^{15} (mass 15), the latter being roughly one per cent of the former. Thus, the largest peak present is mass 28, formed by the ion $N^{14}\ N^{\cdot 4+}$. (The plus sign indicates that this is a positively charged molecule—in other words an ion.) However, there is a weak peak at mass 29 ($N^{14}\ N^{15+}$) and an extremely weak one at mass 30 ($N^{15}\ N^{15+}$). For the use of N^{15} as a tracer in chemical or biological studies the mass 29 peak would be of importance. (A tracer is used as a means of tagging, and later identifying, particular atoms in reactions or processes in which other atoms of the same element are present, in order to trace the course of this element throughout the process without changing the nature of the reaction.) All of these peaks are formed by simple ionization of the nitrogen molecule by electron impact. When the electron hits the nitrogen molecule it may split (dissociate) the molecule producing an atomic nitrogen ion. Considering only the more abundant isotope N^{14} the simple ionization gives a peak at mass 28, whereas the combination of dissociation and ionization gives a peak at mass 14. Thus

$$N_2 \longrightarrow N_2^+ + e^- \text{ (ion of mass 28)}$$
$$N_2 \longrightarrow N + N^+ + e^- \text{ (ion of mass 14)}$$

Where $e-$ represents the electron ejected in the reaction. In this case simple ionization is far more probable; i.e., the ion current corresponding to mass 28 is much larger than that at mass 14.

In some cases it is more probable to dissociate the molecule by electron impact than it is simply to ionize it. This is particularly true of hydrocarbons. For instance in normal butane ($C_4\ H_{10}$) with a parent mass at 58, the largest mass ($C_3\ H_7$) in the spectrum is at mass 43. Thus

$$C_4\ H_{10} \longrightarrow C_4\ H_{10}^+ + e^- \text{ (ion of mass 58)}$$
$$C_4\ H_{10} \longrightarrow C_3\ H_7^+ + CH_3 + e^- \text{ (ion of mass 43)}$$

A great deal of study has been made in recent years of the energy of the electron beam at which these various fragments appear, and it has been possible to correlate these results with thermo chemical data. In a molecule like normal butane, with a large number of component atoms, many masses are present in the mass spectrum due to the dissociation of the molecule by electron impact. A portion of the normal butane spectrum is shown in Fig. 3. This spectrum can be obtained by continuously varying either the ion accelerating voltage or the magnetic field. This so-called "cracking pattern" is helpful in an analysis of a mixture of normal butane and its isomer iso-butane. (Isomers are compounds having the same molecular weight; they are composed of the same

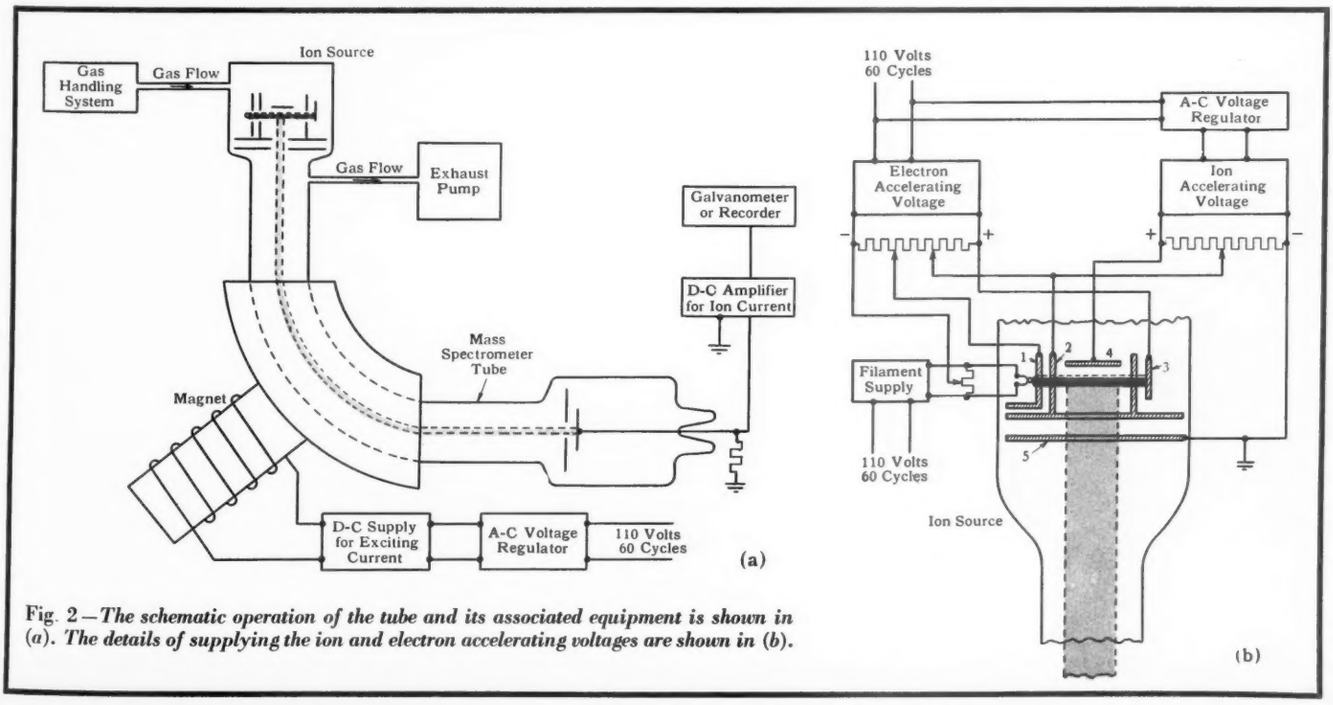


Fig. 2—*The schematic operation of the tube and its associated equipment is shown in (a). The details of supplying the ion and electron accelerating voltages are shown in (b).*

TABLE I—ANALYSES OF HYDROCARBON BLENDS

Component	Per Cent of Total				
	Blend 1	Blend 2	Blend 3	Blend 4	Blend 5
i–C_4H_{10}					
Synthetic	22.4	41.6	....	24.4	51.9
Mass Spectrometer	23.4	41.7	....	24.0	52.0
n–C_4H_{10}					
Synthetic	25.4	41.2	....	14.2	48.1
Mass Spectrometer	26.1	41.4	....	13.7	48.0
α–C_4H_8					
Synthetic	26.2	....	3.7	....	....
Mass Spectrometer	25.3	....	4.1	....	....
cis–β–C_4H_8					
Synthetic	....	....	18.3	25.6	....
Mass Spectrometer	....	....	20.0	26.6	....
trans–β–C_4H_8					
Synthetic	....	....	31.1	....	....
Mass Spectrometer	....	....	28.6	....	....
γ–C_4H_8					
Synthetic	26.0	....	....	28.8	....
Mass Spectrometer	25.1	....	....	28.6	....
1, 3–C_4H_6					
Synthetic	....	17.2	46.9	7.0	....
Mass Spectrometer	....	16.9	47.3	7.1	....
Air					
Synthetic	0	0	0	0	0
Mass Spectrometer	0.30	0.42	....	0.16	0.49

elements united in the same proportion by weight, but differing in one or more properties because of difference in structure.) Since the cracking patterns of these isomers differ, an analysis can be made in spite of the fact that both parent masses are the same. In the region shown on the record the successive masses result when a successively greater number of hydrogen atoms are split from the parent ion, $C_4 H_{10}$. The peak at mass 59 is contributed by the heavy carbon isotope C^{13}. In other cases the cracking pattern causes complications because the butanes contribute masses at all points in the mass spectrum at which hydrocarbons of lower mass would appear. For instance, an analysis of a mixture of normal butane and butadiene ($C_4 H_6$ with the parent ion as mass 54) would require that we first subtract the contribution to mass 54 from the normal butane; the remainder of the current at mass 54 is then contributed by the butadiene. As all the equations are linear, this problem can be set up mathematically and solved for a fairly complicated system.

Clearly the mass spectrometer is an extremely useful tool for analyzing hydrocarbons for impurities of higher molecular weight than the main components because there is no conflict in masses, and the impurities stand out uniquely. It is also generally true that hydrocarbon analysis by the mass spectrometer becomes most difficult when the components have the same or nearly the same molecular weight.

The results achieved in quantitative analysis of five blends

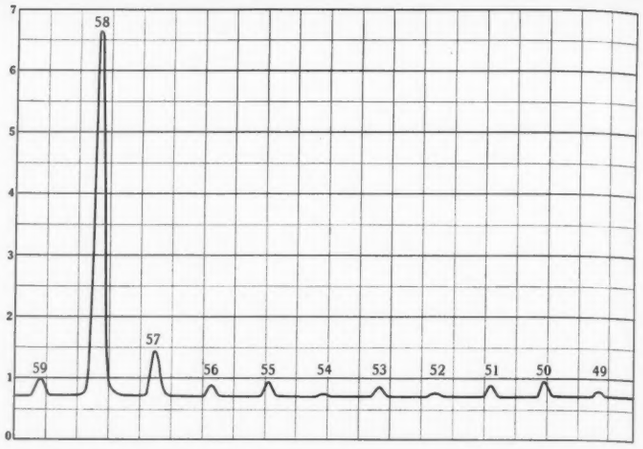


Fig. 3—*A portion of the spectrum of normal butane, which has a great number of component atoms, showing the large number of masses present due to the dissociation of the molecule by electron impact.*

of hydrocarbon gases are shown in table I. The blends were synthetized by a third party, and the findings, when using the mass spectrometer, are compared in each instance with the actual amount of the gaseous component in the blend. This is typical of the operation of the mass spectrometer when resolving masses of nearly the same molecular weight. In this example, all the parent masses appear at the three mass numbers 54, 56, 58. The addition of components to this mixture having masses somewhat removed from these would not, in general, have complicated the analyses.

The problem of hydrocarbon analysis has been discussed at some length not only because it is a difficult one, but also because in this field of analysis it is immediately applicable to the synthetic rubber and aviation gasoline programs so important to the immediate war effort.

The value of the spectrometer as an analytical tool in the analysis of hydrocarbons alone well justifies its development. However, already in evidence are other promising fields of application, such as leakage testing, outgassing of vacuum equipment, metallurgical analyses, purity of controlled furnace gases, automatic controls of processes where it may be important to measure the relative quantity of a desired constituent or to detect presence of an undesirable element and so on. Any of these applications might conceivably require simpler and consequently less expensive instruments than the ones now used for analyses in laboratories.

The main point of interest is that the mass spectrometer is commanding ever-increasing use in widely separated fields of applications. Time will only enhance its merit.

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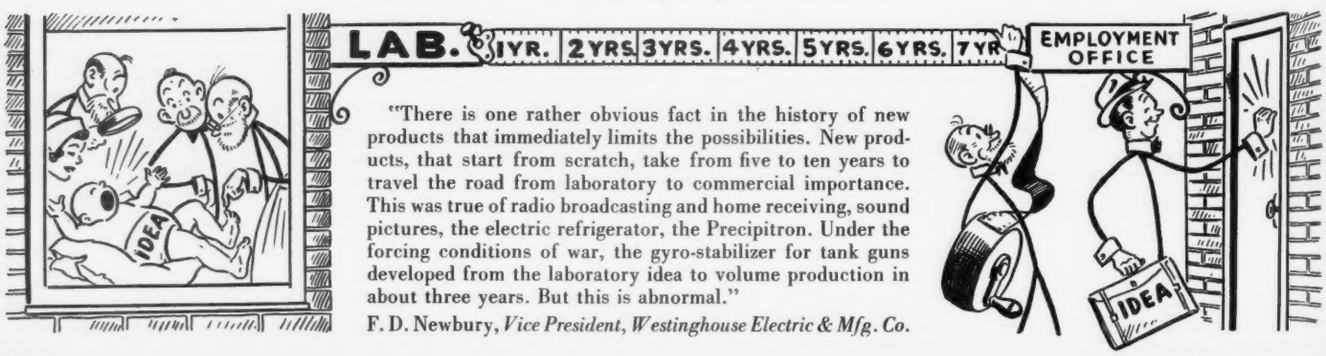


"There is one rather obvious fact in the history of new products that immediately limits the possibilities. New products, that start from scratch, take from five to ten years to travel the road from laboratory to commercial importance. This was true of radio broadcasting and home receiving, sound pictures, the electric refrigerator, the Precipitron. Under the forcing conditions of war, the gyro-stabilizer for tank guns developed from the laboratory idea to volume production in about three years. But this is abnormal."

F. D. Newbury, *Vice President, Westinghouse Electric & Mfg. Co.*

Principles of High-Speed Relaying*

DIFFERENT types of relaying, such as overcurrent, distance, etc., are often thought of as distinct types that have been evolved by somewhat accidental discoveries of new principles. However, the relaying practice has now arrived at the point where each type can be considered to be the embodiment of a definite principle, conceived simply by considering what possible uses can be made of the available currents and voltages. The three line-to-neutral voltages can be combined with each other to produce the line-to-line voltages, the positive-, negative-, or zero-sequence components of voltage or other combinations. Similarly the "delta" currents, the symmetrical components of the line currents and other current quantities, can be derived.

With all of these quantities available, however, there are only certain things that can be done with them. All relaying principles must be based on these fundamental operations, regardless of their historical development. Relays can be made to operate on the change in the magnitude of a single quantity or the change in the relation between two or more quantities, with regard to magnitude, phase, or both.

Voltage Alone

Change in voltage magnitude is often a means of indicating that a fault has occurred on the system. However, when several circuits are directly connected on a common bus, the same voltage magnitude at the relays can be obtained for faults in any of several locations, nullifying voltage indication as a means of locating the fault. Hence, devices responding to voltage alone are used primarily as auxiliary devices for detecting the presence but not the location of a fault.

Comparison of Voltage Magnitude

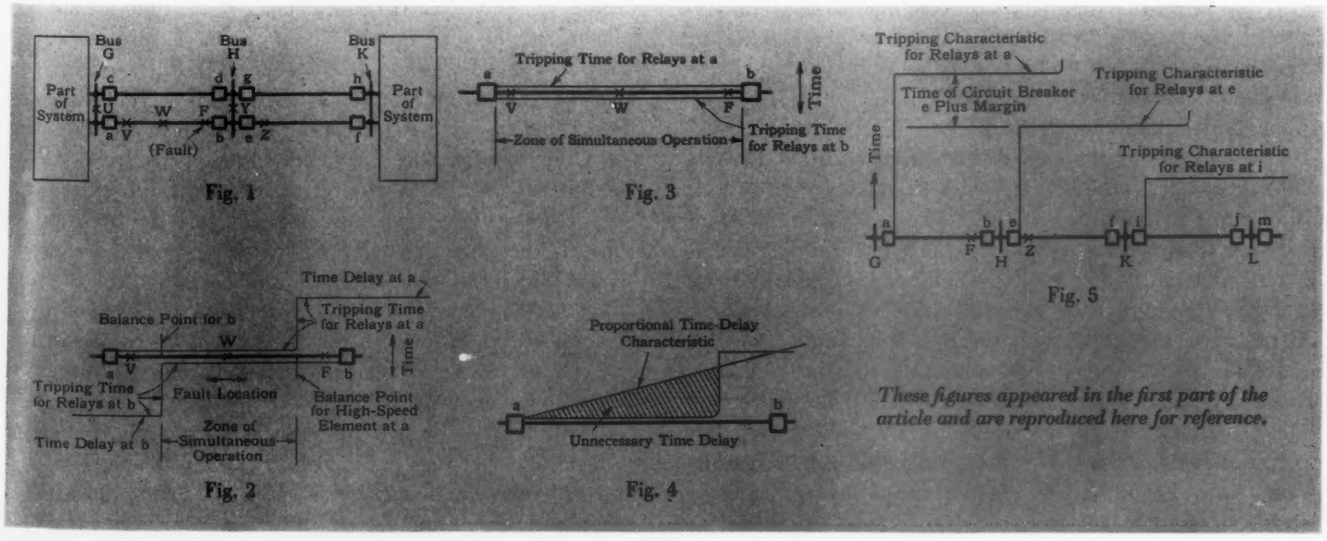
Comparison of the magnitude of two or more voltages at the same relay location is another method of detecting the presence of a fault. Little advantage is found as compared with the measurement of a single magnitude, except in special cases, so that the method is seldom used.

Current Magnitude, Overcurrent Protection

Change in current magnitude is the simplest and most obvious indication of a fault. It is, of course, evident that a large increase above full-load current denotes an undesirable condition on the circuit, usually a fault, and relays responding to overcurrent are still the most common devices for determining fault location. However, because of changes in the system, faults occurring at a given location do not always give rise to the same currents. The type of fault, that is, whether the fault is single line to ground, double line to ground, line to line, or three phase, causes large variations in the magnitude of fault current. In addition, impedance in the fault itself may materially reduce the fault current below the possible maximum value. In some cases large changes in connected generating capacity or in system connections cause the fault current at one time to be less than the load current at another time.

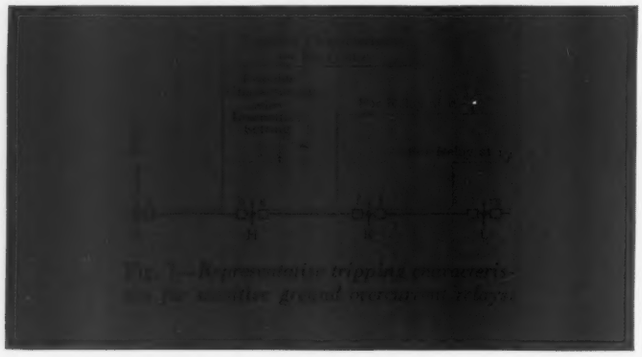
For all these reasons, relays responding to current magnitude alone are not capable of accurate fault location. As a

*This is the second of a two-part article on this subject by W. A. Lewis. The first appeared in the August, 1943, issue, p. 91.


Bus G
Bus H
Bus K
Part of System
Part of System
(Fault)
Fig. 1
Tripping Time for Relays at a
Tripping Time for Relays at b
Zone of Simultaneous Operation
Time
Fig. 3
Tripping Characteristic for Relays at a
Time of Circuit Breaker e Plus Margin
Tripping Characteristic for Relays at e
Tripping Characteristic for Relays at i
Time
Fig. 5
Time Delay at a
Balance Point for b
Tripping Time for Relays at a
Tripping Time for Relays at b
Fault Location
Balance Point for High-Speed Element at a
Zone of Simultaneous Operation
Time Delay at b
Fig. 2
Proportional Time-Delay Characteristic
Unnecessary Time Delay
Fig. 4
These figures appeared in the first part of the article and are reproduced here for reference.

result, when high-speed relaying is attempted, the zone of high-speed operation is subject to large variation. The effect on the relays at *a* is shown in Fig. 6. A similar variation occurs for the relays at *b*.

The tripping characteristic is limited by the fact that the high-speed element of the relays at *a* must not operate for any fault at *F*, because it would then be in danger of operating for a fault just to the right of *b*, outside of the protected section. An overcurrent relay operates for any current in excess of its setting, and the maximum current in the relay at *a*, for a fault at *F*, must therefore be less than the setting of the high-speed element of the relays. As the fault is moved to the left, closer to the relays at *a*, the currents through the relays at *a* increase, and a point is soon reached where the current is sufficient to operate the relay, if system conditions



produce maximum currents. This gives rise to the solid-line tripping characteristic. If system conditions produce smaller fault currents, the fault must be moved much closer to *a* in order to produce a current above the relay setting, and for minimum currents a characteristic as given by the dotted curve may be obtained. With minimum currents the zone of simultaneous operation becomes extremely small, and in some cases may not exist.

This variation in tripping characteristic is the greatest disadvantage of overcurrent relaying. The magnitude of the variation depends upon the day-by-day changes in the system and their effects on fault-current magnitude. Where the change is not large, overcurrent relaying can be successfully used, as indeed it is today. Where the change is great, the zone in which fast clearing occurs becomes small, and more precise types of relays are necessary to obtain adequate high-speed fault clearing.

For faults involving ground, particularly single-line-to-ground faults, it is frequently found that resistance at the point of contact with the earth limits fault currents to well below the maximum possible and often to values substantially less than normal load currents. To obtain proper operation on such faults, a separate ground relay is normally used, energized by the residual current formed by the vector sum of the three line currents, or, what is essentially the same thing, the zero-sequence component of the line currents. This relay current is nominally zero during normal conditions, so that this type of relay may distinguish very low values of fault current. However, when the time-delay elements of the ground relays are given such low settings, the relays for several sections in series may tend to trip when a fault with low fault resistance occurs. To avoid incorrect tripping in these cases, cumulative time settings become necessary, much as in Fig. 5, except that the high-speed elements are superimposed, to give relay characteristics as shown in Fig. 7. The essential point is that the time-delay element of the ground relay at *a* has been given such a sensitive setting that it tends to trip for a maximum-current fault between *K* and *L*. To prevent its actually tripping on such a fault, the time delay must be made greater than for the relay at *e* by an ample time to allow circuit breaker *e* to open, and the relay at *e* must be similarly coordinated with the relay at *i*, etc. If the relay at *a* is given a less sensitive current setting, so that it will not tend to trip for any fault beyond the high-speed zone of the relay at *e*, the normal characteristic shown by the dotted line can be used. For ground faults, sensitivity is often more important than high speed, so that the characteristic given by the solid lines is usually encountered. By using three relay elements, one high speed, one with the delay corresponding to one circuit-breaker time, and the third with longer delay, all the desirable features are obtained, giving the characteristic for the relay at *e* of both the dotted and the solid lines.

As time delay in the clearing of ground faults is considerably less serious than in the clearing of line faults from the standpoint of the effect on system stability, it is quite common to find overcurrent protection for ground faults combined with more accurate means for determining the location of line-to-line faults.

Comparison of Currents

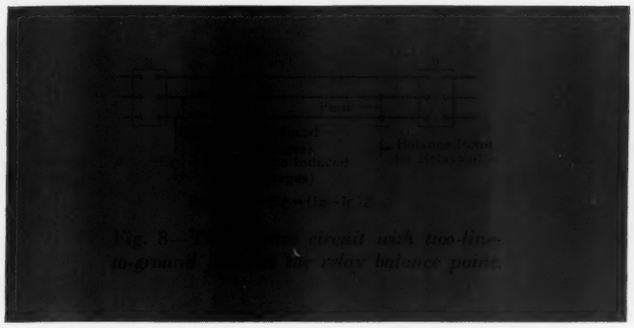
Balanced-Current Protection—Because the variation of current magnitude with system conditions is one of the principal sources of inaccuracy in overcurrent relaying, we are led to ask whether the relay current can be compared with some other current that is affected similarly, so that this variation is compensated. Where two parallel circuits are connected to common buses at both ends, the currents in the two circuits can be compared, giving rise to so-called balanced-current protection. If the impedance of circuits *ab* and *cd* of Fig. 1 are equal, all currents that flow to loads or to short circuits at bus *H* or beyond on the right, or at bus *G* or beyond on the left, are shared equally between them. However, when a fault occurs at say *W* on one of the lines, the current flowing through *a* to *W* is much greater than that flowing through *c* to bus *H* and then back to *W*. Hence a relay at *a* that compares the magnitudes of the currents in *a* and *c*, and responds to the difference, either in absolute magnitude or in percentage, is operated positively for a fault at *W* but has no tendency to operate for any fault external to the *ab* and *cd* circuits. As the fault location is moved toward bus *H*, the currents being compared become more nearly equal. Finally a point is reached at which the difference is too small for the relay to recognize, without risk that it will respond to an external fault, because of difference in line impedance, current-transformer characteristics, or other minor circuit factors.

With faults at any location between *a* and the balance point, high-speed operation results, thus providing the same type of relay characteristic as in Fig. 2. For faults between this balance point and circuit breaker *b*, the relay at *a* is un-

able to respond until the opening of circuit breaker *b* alters the current distribution. When *b* opens, the current through *a* increases, that in the parallel line reverses, and the change is sufficient to cause tripping of *a* as soon as breaker *b* has opened. Hence the tripping characteristic follows that of Fig. 2. However the delay is automatic, instead of being provided by a second time-delay element in the relay, and is always the shortest time consistent with proper operation.

This type of protection is much less affected by system variations than is one based on current magnitude, because of the current comparison. It is, however, operative only when two parallel lines are in service, and therefore must be used as a supplement to single-line protection and cannot be used on single circuits.

The same type of protection can be used at *b* in Fig. 1, provided the right hand side of the system can always be counted upon to supply an appreciable part of the fault cur-



rent for any fault on *ab*. If not, for a fault at *W* or *F* the current entering through *d* is equal in magnitude to the current leaving at *b*. Hence, a simple magnitude comparison is not effective, and a comparison involving both magnitude and relative direction is not indicative of which circuit is incoming and which outgoing, because of the periodic reversal of the alternating current. For such cases the difference in current must be further compared with an appropriate voltage, in the manner of a directional relay, as discussed below.

Balanced-Current Pilot-Wire Protection—The ideal relaying principle involves the comparison of the currents at one end of a line section as at *a*, with the corresponding currents at the other end, as at *b*. When the fault does not lie between *a* and *b*, these currents are substantially equal in magnitude and phase. When any fault occurs within the line section, the currents at the two ends, on at least one phase, are no longer equal. Relays responding to this difference provide high-speed tripping for faults anywhere within the line section. Such a comparison requires some form of pilot channel, with its attendant cost and operating problems.

Suitable networks are available that combine the currents of the three phases into a single current quantity at each end. These two currents can then be compared over a two-wire pilot channel. By proper choice of the combined current, an effective comparison can be made for short circuits of any type on any phase.

A carrier-current channel for this type of comparison has not been found effective because it involves elaborate equipment for modulating the carrier wave in order that information regarding the magnitude and phase of the 60-cycle current can be transmitted at high frequency. Hence, when a carrier channel is used for comparison, other relaying principles are normally utilized.

Differential Protection—A principle similar to the current comparison just mentioned is more widely used than any other for the high-speed protection of apparatus such as generators, motors, transformers, and buses. Here the problem of distance, necessitating long pilot circuits, does not enter. Because the relays respond to differences in current, this protection is known as differential protection.

Comparison of Current and Voltage

Distance Protection—The comparison of current and voltage magnitude at the relay location gives rise to the type of relaying generally known as distance protection. The principal objection to overcurrent protection is that the balance points, which mark the boundaries between high-speed and delayed tripping zones, are not fixed but shift considerably with changes in system conditions, as shown in Fig. 6. Relay performance will be improved if this variation can be eliminated. The principle by which this is accomplished is illustrated in Fig. 8 for a simple case.

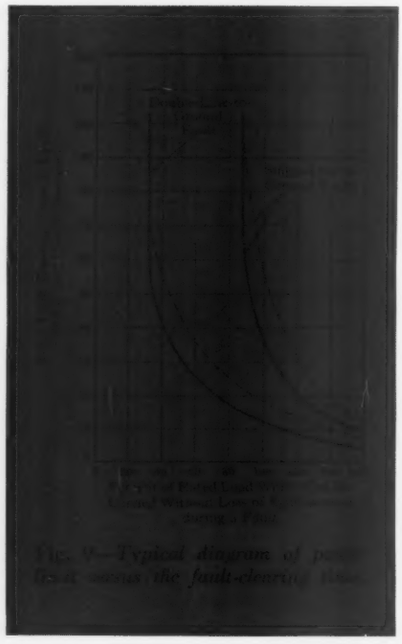
Assume that a two-line-to-ground fault occurs at the balance point, where it is desired that the high-speed relay element at *a* just balances between operation and non-operation. The currents in the two faulted conductors at the relay location are I_B and I_C. If the impedance per phase of the circuit between circuit breaker *a* and the fault is *Z*, then the voltages at the relay location are the *IZ* drops in the faulted phases plus any induced voltages caused by magnetic effects from currents in neighboring parallel conductors. The usual three-phase circuit can be assumed symmetrical or transposed, and therefore the voltages induced in both phases by any currents in neighboring parallel conductors are the same. When the line-to-line voltage is formed by taking the difference of the two line-to-neutral voltages, any such induced voltages cancel and the result is proportional to the difference of the two line currents, as shown in the figure. Hence, if the relay is operated by the difference of the line currents in two faulted phases and restrained by the corresponding line-to-line voltage, the same proportionality factor *Z* between the operating and restraining forces is maintained for all currents, even should system conditions change radically.

The same relation holds for a line-to-line or three-phase fault at the same location. Other relays connected to the other pairs of conductors are affected similarly when the fault occurs on those phases. Hence, by using a relay that compares current and voltage magnitudes, the greatest cause of difficulty with overcurrent high-speed relaying is eliminated.

For single-line-to-ground faults, a different and more complex current and voltage combination must be utilized to obtain the desired compensation, which considerably complicates this type of protection. Because the necessity for maximum relaying speed is not as great on single-line-to-ground faults, ground overcurrent protection is commonly used even when distance protection is used for faults involving two or three phases.

A further modification can be made by introducing the phase relation between the operating current and the restraining voltage of the relay. The proportionality factor be-

tween operating current and restraining voltage can then be made to be the reactance instead of the impedance. The purpose of this modification is to reduce the remaining variation of balance point caused by the presence of resistance in the fault itself, which was ignored in the derivation in Fig. 8. However, when currents out of phase with each other flow to the fault from both ends of the circuit, the expected benefits may not be fully realized. Both forms of distance protection are extensively used for protection against two-phase and three-phase faults on the more important circuits.



To insure that every fault will be cleared, even if fault resistance be high, and to provide back-up protection if other relays fail, distance relays of both impedance and reactance types are usually provided with three elements or three time zones, so that the available tripping characteristic is that of the solid and dotted combination curve of Fig. 7. Other distance relays are available with proportional tripping characteristics, as in Fig. 4, and a combination relay, with a high-speed first-zone element and a proportional-time second element, thus using the best features of both characteristics shown in Fig. 4, can also be had.

Directional Protection—Not only must the distance to the fault be determined, within the appropriate zone, but the direction of the fault from the relay must be verified. In general the voltage at the fault, from the faulted phase to ground or between the faulted phases, is less than the corresponding voltage at relay locations, so that the direction of the fault from the relay is determined by the direction in which the appropriate voltages are decreasing. This could be determined directly only by comparing the voltages at two separated points, but the change in voltage along the line and the impedance of the line determine the phase relation between the voltage and current. Hence comparison of the relative phase positions of appropriate currents and voltages is the practical method for determining the direction of the fault.

Comparison of Relay Action

Pilot-Wire and Carrier-Current Protection — Another and final relaying principle is the comparison of relay actions at different points. As applied to transmission circuits it means comparing the action of relays at the terminals of the line over a pilot channel, either direct wire or carrier current. In connection with Figs. 2 and 3, it has been indicated that the time delay at *a* can be eliminated if the relays at *a* can be informed immediately of the relay action at *b*, because the relays at *b* can determine whether a fault to the right of the balance point for *a* is within or outside of the line section *ab*. The signal required over the pilot channel is merely a positive or negative indication and is therefore the simplest possible type of signal to be transmitted. Both pilot-wire and carrier-current signaling is used, but where pilot wires are available, the current-comparison method is more frequently preferred. With either method, high-speed relay operation is obtained for all faults within the line section.

Selection of Relaying Method

Most of the factors that make high-speed relaying desirable are difficult to evaluate concretely. The value placed on them by engineers differs materially. On the smaller systems where short-circuit currents are limited, the risk of damage to insulators and of burning down conductors is not great, even with relatively long fault-clearing times. However, as the system capacity is increased, the point where serious trouble may be encountered is gradually reached and, after a few cases of trouble have occurred, the merits of fast relaying are more readily appreciated. As more exacting manufacturing processes are developed, and lighting customers become more critical of light flicker and fluctuation, more attention must be paid to reducing the duration and magnitude of voltage dips, and the demand for faster relaying becomes more pressing. As loads are increased, the stability limit is gradually approached, and after the first case of instability caused by slow fault clearing, high-speed fault clearing becomes much more important.

On long-distance or heavily loaded circuits, stability limits may make high-speed relaying and fast circuit breakers a necessity, if the loads are to be safely carried. In individual cases a stability study carried out on an a-c network calculator, or mathematically in simple cases, shows what fault-clearing times are necessary, if stability is to be maintained at a particular load. Usually, a two-line-to-ground fault at the worst location, without fault resistance, is taken as the most severe fault to be withstood, on the assumption that the probability of the more severe three-phase fault under the same conditions is too slight to be given consideration. The cost of a system that can withstand a three-phase fault is usually so much greater that it cannot be economically justified. A curve can be drawn showing the load that can be carried with stability, as a function of the time of fault clearing. A typical one is shown in Fig. 9. If pilot-wire or carrier-current relaying is used, so that both ends of the circuit open simultaneously, the permissible fault duration is given by the solid line. If other forms of relaying are used, so that the circuit breakers open sequentially, the first circuit breaker must open sooner, but the severity of the fault is thereby reduced, and the total clearing time is somewhat increased. Hence, for sequential circuit-breaker operation, the total clearing time may be as shown by the dotted curve of Fig. 9.

Similar curves are also shown for a single-line-to-ground fault in the same location. The permissible times for a single-line-to-ground fault are much greater than for the two-line-to-ground fault, so that high-speed relaying of single-line-to-ground faults is much less important than high-speed relaying of two-line-to-ground faults, from the stability standpoint.

What's New!

Measuring Mechanical Vibrations

VIBRATION is the enemy of precision. For successful operation of precise machines, vibration troubles must be removed. However, until the amplitude, frequency or some other inherent characteristic of a vibration is disclosed, its total elimination cannot successfully be undertaken. An improved device for measuring mechanical vibrations—developed at the Westinghouse Research Laboratories—is simple, accurate, and versatile in its applications to most problems.

The Westinghouse vibrograph is applicable to the analysis of vibrations encountered in machinery. It gives high precision results between 60 and 15 000 cycles per minute, but is also useful for vibration analysis considerably outside of this range. It records an amplitude range of from less than one ten-thousandth inch to as high as one sixteenth inch.

Fundamentally, a vibrograph consists of a frame containing a mass suspended by a weak spring. A pointer attached to the mass indicates relative motion between the frame and mass when the frame is applied to a vibrating body. Ordinarily the frame is placed upon the vibrating body and indicates displacement in one plane only. In cases where there is lack of physical space upon which to rest the vibrograph or when the mass of the frame of the instrument affects the vibrations, the instrument is hand-held and vibrations are transmitted by means of a prod. Replacing the pointer with a stylus or pin acting on a moving tape records the vibrations graphically.

In the vibrograph developed by Mr. H. C. Werner and his associates, both seismic and prod applications are combined in the one device. The manner of mounting and centering the mass of the instrument permits operation in any position. The stylus describes a track of the vibration on a moving ribbon of celluloid and is viewed with a low-power microscope. Incorporated in the vibrograph is a newly devised timing device that leaves a trace on the ribbon allowing calibration of the vibrations under observation. Weighing but eight and one-half pounds, the vibrograph measures four by five by seven inches.

Combining compactness with simplicity and unusually wide range, the vibrograph is extensively used in industry to investigate vibration of high-speed rotating equipment such as turbines, small motors and motor-generator sets. It can be also used for certain phases of plane-vibration tests and similar work related to the war effort.

New Fluorescent Lighting Hood

OLD Man Mars has taken a hand in writing specifications. Not only must equipment perform and be competitively priced, but the included amount of strategic materials is limited. In covers for fluorescent lighting fixtures, WPB has set a limit of three pounds on the steel content, exclusive of the ballast, for individual units using two and three 40-watt lamps.

The cover assembly offers a fireproof enclosure for the electrical wiring and is a rigid support for the reflector and lamps. It must maintain exact spacing of the lamp holders. A light gauge metal is used, and the ballast is mounted on top of the cover. This provides improved circulation of air for cooling and reduction of the hood depth from three inches to ⅝ inch. The weight of the cover was reduced from 10 pounds to 2.88 pounds. To meet the Underwriters' Laboratory requirements, the reflector which closes the wire way is fireproofed by a special treatment prior to the enameling operation.

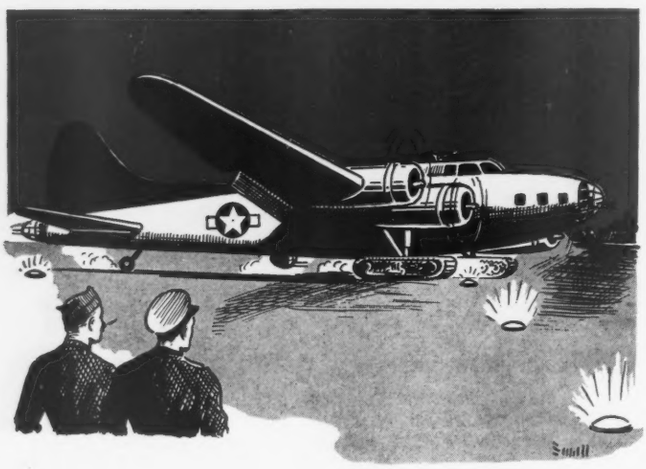
Available in the two- and three-lamp, 40-watt sizes, and also the two-lamp, 100-watt size, these luminaires are for use in installations calling for individual or continuous strip mounting.

After Flying—Helping Them to Land

So closely tied are the elements of civilization (which include the waging of war) that a shift of one factor causes far-spread reverberations. As bombers became increasingly large and heavy, wheels proved inadequate for landing gear on many terrains. A new landing gear, utilizing endless tracks as on a tractor, has been devised. But like everything new, it caused repercussions in unlooked-for places. Airport contact lights which were regarded as structural marvels in that they withstood a dead-weight loading of 100 000 pounds, the equivalent of a taxiing bomber, are now inadequate. Gone with the wheels are the resilient rubber tires. Now heavier bombers are dealing mightier blows in taxiing without the cushioning effect of pneumatic tires. One hundred thousand pounds is not enough.

In redesigning the contact lights originally, when war machines played hob with peacetime lights, Westinghouse engineers were posed with the problem of making them stronger and better, with no increase in size. It is estimated that there are over 125 000 contact lights sunk in their concrete emplacements about the country. Dimensionally, then, the lights are frozen for the duration because of the magnitude of the replacement job for any but a light that fits exactly the standardized emplacements now in existence.

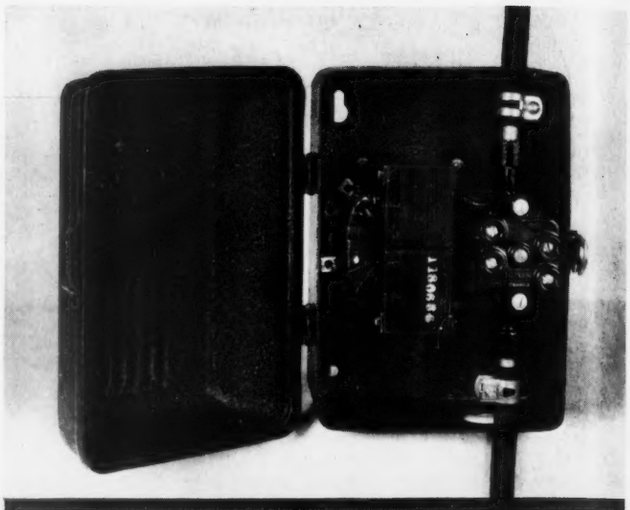
Nevertheless, the rating of the contact lights in 1942 was raised from 35 000 to 100 000 pounds dead-weight loading. Now the sights have again been elevated. The utmost in structural design has been lifted from the bridge builders and the toughest and strongest alloys emanating from metallurgical laboratories have been used to meet the new conditions without any increase in size. Progressing steadily from 100 000 pounds dead-weight load, this year's efforts have carried through 150 000, 160 000, to 200 000 pounds. This apparently is the ceiling of the structural strength needs at this time. What new demands may come are not known. Sufficient to the day are the engineering problems thereof when the impossible merely takes a little longer.



Electro-Thermostatic Flow Switch

Like other vital war equipment water-cooled ignitron tubes must be protected against damage. These electronic rectifier tubes require a certain flow of water to maintain proper operating temperature. If this is inadequate, the life of the tube is shortened, and if the flow is cut off, the ignitron will be destroyed, if continued in operation. The newly developed Westinghouse electro-thermostatic flow switch gives positive protection from this possible hazard.

The one-turn secondary of a 100-watt transformer is short circuited through a piece of high-resistance stainless-steel pipe, which is connected as a portion of the cooling system. Forced into intimate contact with this tube is a metal plate upon which is mounted a positive-acting, two-pole thermostatic switch of the disc type. This is normally closed. The flow of coolant keeps the temperature of the stainless-steel tube at such a level that the disc thermostat is not actuated by heat conduction. Should the cooling system fail, however, the temperature of the pipe, which short circuits the transformer secondary, rises and the thermostatic switch operates. One contact opens to disconnect the flow-switch transformer, while the other opens to disconnect the firing circuit of the ignitron, thus preventing its operation until a safe operating temperature is reached.



The thermostat on the right operates to open an electrical circuit should an interruption to the flow of coolant occur.

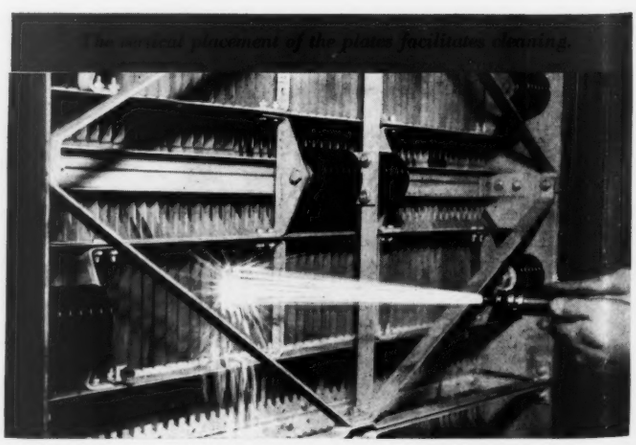
This flow switch is available in either the 1½-gallon or 3-gallon per minute size for 220/440-volt rating at either 25 or 50/60 cycles. Furnished with or without an enclosing steel cabinet, all parts are assembled for easy replacement of parts. The mounting space required is about seven by nine by five inches.

Precipitron Cleaning Now Easier

Simplicity and efficiency in maintenance are engineering goals equally as desirable as simplicity and efficiency in operation. Constant attention to this phase of designing has led to installing the collector plates in the Westinghouse Precipitron vertically instead of horizontally. Without changing the size or operating characteristics the cleaning time has been materially reduced.

The Precipitron, by electronic electrostatic action, gives the impurities in the air an electrical charge. These charged particles are blown between plates of opposite polarity which attract the charged particles to them, and there they remain. The cleaned air passes on through. Obviously, the plates require cleaning periodically. In large installations this is done by washing down with a hose. There are two drawbacks to a swift, thorough job—water tends to remain on the horizontal plates, and it is difficult to clean the under sides of the plates.

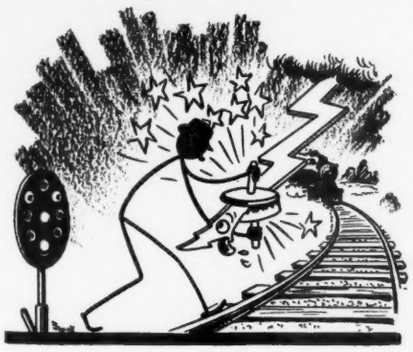
By mounting the plates vertically, the cleaning water runs off by gravity, and no water collects on the plates. The problem of cleaning the under sides of the plates is, of course, eliminated. The cost and time involved in cleaning maintenance work has been reduced. The reduction of the cleaning time is achieved with no change in the basic requirements of the device and no loss of air-cleaning efficiency, being a change in physical arrangement only.



The vertical placement of the plates facilitates cleaning.

PERSONALITY PROFILES

E. BECK has spent a long time working with phenomena that don't last very long—only a few millionths of a second. The bulk of his engineering career since graduating from Columbia in 1917 has been occupied with building better traps for lightning. He has had an intimate hand in developing some of the basic protective devices of today, such as the Autovalve arrester and the De-ion tube. But as he went along—he is now manager of the protective devices section at Westinghouse—he garnered valuable experience on short-lived phenomena with other equipment such as surge generators (those mimics of natural lightning), cathode-ray oscillographs



(his newest one writes down things that happen in a fifth of a millionth of a second), x-ray machines, and various devices for studying natural lightning. He once wrote a series of articles, under the heading "Traveling-Wave Primer," which were so popular the stock of reprints went with the speed of lightning. Aside from his engineering talents, four occupations characterize Ed Beck, his everpresent pipe, a love for philosophical discussions, his garden (he is no victory garden novice), and his skill on the grand piano with Beethoven and other masters. Incidentally Beck holds the record for authorship in *Westinghouse ENGINEER*. This is his third appearance. Nice habit!

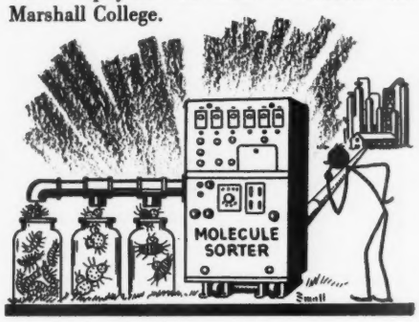
* *

Capacitors for power-factor correction are one fifteenth as large as they were 25 years ago when *R. E. MARBURY*, just out of Georgia School of Technology, first started working with them. And he has had a major part in nearly all the steps of that reduction. He was on hand at Westinghouse in 1918 when the trial installation of capacitors was made, and helped establish their commercial production in 1924. At that time capacitors were applicable only for voltages of 2300 and above because of their high cost. Marbury was largely responsible for the first low-cost 230- and 440-volt units that came out in 1925. He was in charge of the development that led to the Westinghouse fireproof, synthetic-impregnated capacitor in 1934 and to the first capacitor suitable for outdoor installation, in 1937. He has, needless to say, been in charge of capacitor engineering at Westinghouse for many years. Much of his effort has been spent in capacitor application, which has included the solving of problems in connection with arc furnaces, resistance-welding machines, and at present, many of those attendant upon military communication.

Marbury got the jump on OPA about two years before it was even established by converting his furnace from gas to coal. He has designed and built his own completely automatic coal-firing control, even to the outside-temperature control unit for operation of the shaker. The control does everything but carry out the ashes and pay the coal bill.

* *

Subjects of Doctor of Philosophy theses do not have the reputation of being of great practical significance. To *DR. JOHN A. HIPPLE* has come the unusual experience of seeing the mass spectrometer, subject for his doctor's degree from Princeton in 1938, develop into a practical device of importance in the war program. He came directly to Westinghouse Research Laboratories as the first research fellow and continued his work on the spectrometer. Largely as a result of his efforts it has now reached the stage of a practical production tool for the petroleum and chemical industry. He has been recently engaged further in familiarizing petroleum and chemical experts in the use of this new industrial device and cooperating in its application to their problems. Dr. Hipple's undergraduate work in physics was done at Franklin and Marshall College.

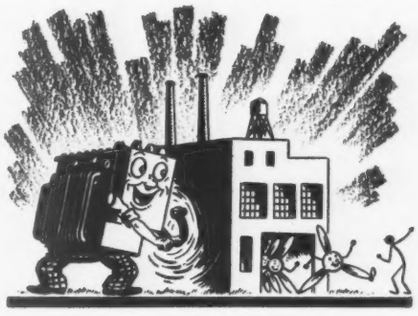


Of the some fifty men whose names have appeared on these pages, few have had as varied engineering experience as *H. E. DRALLE*. His engineering experience spans the two great wars. During World War I, as a member of the staff of the late Dr. Frank Conrad, Westinghouse Chief Engineer, he assisted with such varied problems as presented by development of new meters, redesign of hand grenades, and construction of the first spark radio transmitter for planes. In this war he has helped electrify new pipe lines, has helped bring the mass spectrometer to bear on the wartime problems of oil refineries, and has become a recognized expert in applying electrical apparatus to the making of synthetic rubber. Early in his engineering career, following graduation from the University of Illinois in 1916 (B.S., E.E.), he dealt with electric mining locomotives, arc welding in its earliest stages, and, just after the war, with the electrification of machine tools, and with the use of electrical apparatus in railroad car shops—all this before entering the field in which he is now so well known, petroleum engineering. In 1926 he embarked on a world tour of petroleum centers, stopping particularly in Rumania, Russia, Iran, Burma and the East Indies to assist with specific problems of oil field electrification there, and returned 17 months later after having studied firsthand petroleum production and refining problems of every major field in the world except in South America. This was followed in 1928 by a five months' trip to the capitals of Europe and the headquarters of the large oil firms, and then by a trip into southern Mexico to consult on the electrification of a new field there. Dralle gets around!

During the early 30's he picked up extensive field experience applying gears to industrial machinery. This background of varied experience has led to his present position as manager of Petroleum and Chemical Engineering for Westinghouse. In his off hours he swings a mean golf club, and can do a swell job with the tenor part in any barbershop chorus.

* *

C. E. PFLUG attended the University of Nebraska, obtaining his degree in electrical engineering in 1926. Wishing to learn more in detail what makes electrical apparatus tick he went, upon graduation, to the General Electric Company and spent two years on the electrical test course. But the call of the middle west was too strong for him and in 1928 he went to Wisconsin to work for the Wisconsin Power and Light Company as a substation engineer. A few years later the Nash-Kelvinator Corporation, looking for a young electrical engineer for its automobile plant at Kenosha, Wisconsin, won him away from power-system engineering. For two years he worked at Kenosha, with the automobile production lines parading before him, until the automobile companies joined the colors. He was then selected as plant engineer for the Nash-Kelvinator plant turning out "props" for Army and Navy planes. In the "days that wuz" his hobby was the very real joy of the Advertising Department of the makers of Nash cars. Upon every available opportunity he made use of the fact that his Nash was not only a vehicle but could be quickly converted to sleeping quarters. Camping in this fashion



was his delight. Now he considers himself lucky to be able to get away from work for one Sunday in four or five.

● Capacitors, essential to the operation of both power and electronic apparatus, are themselves improved by electronic controls. The precise, smooth acceleration of these electronically controlled winding machines makes possible the use of extra thin foil.